History of the Ministry of Munitions.

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THE SUPPLY OF MUNITIONS

PART I

AIRCRAFT

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CHAPTER I.

DEVELOPMENT OF AIRCRAFT AND AERIAL POLICY, 1914–18.

I. Growth of the Air Services and their Administration.

(*a*) Introductory.

It is well from the outset to appreciate the bearing of supply conditions upon British aerial policy during the war. The numbers and types of machines furnished had an immediate and powerful influence on questions of policy. Until the end of 1917 there were no aircraft supplies available beyond imperative requirements for purely naval and military purposes. No aerial policy was concerted apart from these purposes, because there was no weapon with which to carry it out. The sole pre-occupation of the authorities at home was to provide the aircraft and equipment demanded by the commanders in the field and with the fleet, while army and naval authorities formed their policy independently according to their resources or the exigencies of the situation. The Royal Naval Air Service and Royal Flying Corps as such had no voice in deciding these policies. They, like any other branches of the Services, were absolutely at the disposal of the War Staffs of the Commanders-in-Chief. For the first two and a half years of the war, the development of aircraft supply was left entirely to the naval and military authorities. The success of enemy aircraft raids towards the end of 1915 caused a demand for aircraft for home defence, and made the question of supply one of a more general national interest. It was at last realised, both by the Services and the people at large, that war under modern conditions had passed from a question of purely professional interest to one of national co-operation. The War Office had already recognised this, and was relying for the bulk of its supplies on the Ministry of Munitions, which had been formed for the express purpose of mobilising the entire capacity of the country for producing munitions. The magnitude of the undertaking, and the fact that the organisation of both Services was involved, caused some hesitation about entrusting aircraft supply to the Ministry, but at the beginning of 1917 the situation with regard to material and labour made the transfer imperative. Towards the end of 1917, when the methods of the Ministry had materialised in increased supplies, a definite aerial policy became not only possible but essential, and the necessity arose for an authority whose exclusive duty it was to study and deal with the problem of war in the air. An Air Council was formed with a combined Air Force under its control, and the valuable work done by the Independent Air Force in the systematic bombing of enemy aerodromes and industrial centres was fully recognised by the Air Council.[1]

[1] *Short History of Royal Air Force*, p. 275.

(b) The Administrative Position, 1914–16.

The Naval Air Service dates from July, 1908, when proposals for the design and construction of a rigid airship were put forward by Admiral Bacon, then Director of Naval Ordnance. It was not, however, until March, 1911, that naval officers were instructed in flying with heavier-than-air craft. Four naval officers formed the nucleus of the Service at that time, and in December a naval school of flying was established at Eastchurch. At about the same time the Air Battalion of the Royal Engineers was formed to supersede the Balloon School. One company was equipped with airships, another with aeroplanes.

The Royal Flying Corps was formed on 13 May, 1912, and provision was made for naval and military wings to be maintained and administered by the Admiralty and War Office respectively. A Central Flying School was established, and the Corps also comprised the Royal Aircraft Factory (since 1911 known as the Army Aircraft Factory), which had been founded in 1905 as a balloon factory.[1] To secure co-operation between the two Services a joint Air Committee was formed with six naval and military representatives. The Committee proved to be unwieldy and automatically divided itself into two sides, one naval, the other military. The tendency throughout was to separate the Services, and in 1914, before the outbreak of war, the Naval Wing of the Royal Flying Corps was changed into the Royal Naval Air Service, so that on the outbreak of hostilities the separation was complete.[2] This dual control is to be ascribed partly to the fact that both the naval and military Departments appreciated the value of aircraft as an auxiliary of their own form of warfare and partly to the difficulty of financing the new service.

The Admiralty developed the aeroplane service outside its normal sphere in order to supplement the inadequate credit which the War Office succeeded in obtaining,[3] but neither wing had been developed in a manner at all commensurate with the needs of the situation when war broke out. In August, 1914, the Naval Wing comprised an airship section with stations at Kingsnorth and Farnborough, and seven aeroplane and seaplane stations with a total of seven airships and some 70 machines. The Military Wing, which was controlled by the War Office, comprised four aeroplane squadrons and an aircraft park, with a total of 179 machines. The two wings had a total combined *personnel* of 197 officers and 1,647 other ranks. On the declaration of war additional stations were hastily formed by the Royal Naval Air Service, and certain vessels were converted into aircraft carriers. A detachment was sent to Belgium with the Naval Division, and airship and seaplane patrols were instituted between the East Coast of England and the Belgian coast, in addition to coastal patrols. All the available pilots and machines of the Military Wing proceeded to France, where they worked in co-operation with the

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[1] In April, 1918, the Royal Aircraft Factory became the Royal Aircraft Establishment. For lighter-than-air craft, see Chap. VI below.

[2] *Parliamentary Debates*, 1917 (*H. of C.*) XCIX, 126.

[3] *Ibid.* 1916. LXXXII, 1575.

British Expeditionary Force.[1] In August, 1914, the War Office was responsible for the aerial defence of the country, but all the squadrons of the Royal Flying Corps were needed in France, and at Lord Kitchener's request the Admiralty became responsible for home defence against aircraft on 3 September, 1914. A Royal Naval Air Service station was established at Dunkirk and, with a view to preventing aerial attacks on England, numerous raids were made by naval airmen upon Zeppelin sheds in Germany and Belgium.[2] Responsibility for home defence was resumed by the War Office in February, 1916.

The building up of the Air Services, and the development of home organisation to keep pace with the ever-growing requirements at the fronts were very difficult problems, since the nucleus left in England for training was very small, only about 20 of the machines left at home being serviceable. For the first two and a half years of the war the expansion of the two branches of the Air Service was developed independently both as to organisation and supply by the naval and military authorities. The Army Council had in 1913 created a separate department, the Directorate of Military Aeronautics, to deal with the new Service, which was subsequently represented on the Army Council. The Admiralty, on the other hand, treated the Royal Naval Air Service in the same way as any other branch of the Navy, dividing the administration between the different Sea Lords. The Director of the Air Department was responsible for advising the First Sea Lord as to exercise and general use of aircraft, the Second Sea Lord as to *personnel* and training, and the Third in matters affecting design and construction of aircraft, while aviation stores were under the administration of the Fourth Sea Lord. Thus the Royal Naval Air Service, as such, was not represented on the Admiralty Board, the members of which had no personal knowledge of aeronautics, but the Director-General of Military Aeronautics, himself formerly a pilot and Commander of the Royal Flying Corps, being a member of the Army Council, was able to speak authoritatively for the Royal Flying Corps.

This policy of dual control no doubt had its advantages, as far as the supply side was concerned, in the early days of the war, when quick expansion was the chief consideration, but the complete separation of the experimental branches of the two Services was soon found to be a cause of waste of effort in research and invention. Competition for engineering talent as well as for skilled labour and material was keen even in the spring of 1915, and became the more pronounced as the Services grew and the adaptation of aircraft for warfare developed. There was no attempt at allocating resources with a view to the national interest as a whole, since there was no independent body to perform such an office.

(c) THE EVOLUTION OF AN AIR MINISTRY.

Towards the end of 1915 public opinion in favour of some co-ordination became very strong. Though it was not at the time proposed to combine the two Services, because it was clear that for a

[1] *British Air Effort During the War.* 1919, Cmd. 100.
[2] HIST. REC./H/1960/1.
[3] HIST. REC./R/172/9.

long time to come the great bulk of the work in the air would be of definitely naval or military character, there was a strong body of opinion in favour of an Air Minister who should have entire control of the Services, and status equal to that of the First Lord and the Secretary of State for War.[1] On 15 February, 1916, the Government appointed a standing Joint War Air Committee to collaborate in and to co-ordinate questions of supply and design of *matériel* for the Naval and Military Air Services. The Committee, however, failed to present an agreed report and was brought to an abrupt end by the resignation of the chairman, Lord Derby, in April, 1916.

As a step towards the eventual establishment of an Air Ministry,[2] the first Air Board was constituted on 11 May, 1916, and was presided over by Lord Curzon. Its duties were defined as follows :—

(*a*) The Board shall be free to discuss matters of general policy in relation to the air, and, in particular, combined operations of the Naval and Military Air Services, and to make recommendations to the Admiralty and War Office thereon.

(*b*) The Board shall be free to discuss and make recommendations upon the types of machine required for the Naval and Military Air Services.

(*c*) If either the Admiralty or War Office decline to act upon the recommendations of the Board, the President shall be free to refer the question to the War Committee.

(*d*) The Board shall be charged with the task of organizing and co-ordinating the supply of material, and of preventing competition between the two Departments.

(*e*) The Board shall organise a complete system for the interchange of ideas upon air problems between the two Services and such related bodies as the (Naval) Board of Invention and Research, the Inventions Branch of the Ministry of Munitions, the Advisory Committee for Aeronautics, the National Physical Laboratory, etc.[3]

The Board was thus entirely advisory in character and, in practice, acted throughout with a more complete knowledge of the military, than the naval, side of the problem.[4]

The result of its investigations was to emphasise the need for co-operation in every direction. The Board was not prepared while war was still proceeding to advocate amalgamation of the two Services, or the creation of an Air Ministry, though this seemed to its members to be the only solution of the Air Service of the future, having regard both to its imperial aspects and to the great expansion to be expected not on the Service side alone, but in respect of commercial and other developments. In a report presented in October, 1916, the Air Board proposed among other things that the administration of the Royal

[1] *Parliamentary Debates*, 1916 (*H. of C.*) LXXX, 94, 126, 132, 152.
[2] *Parliamentary Debates*, 1916 (*H. of C.*) LXXXII, 1607.
[3] Hist. Rec./R/1960/20.
[4] *Ibid.*

Naval Air Service should be liberated from the different departments of the Admiralty and made self-contained, the Chief being given a seat upon the Board of Admiralty, and that supply, design, inspection, and finance for both Services, as well as allocation of supply, should be vested in the Air Board itself. It was recommended that in other respects the duties of the Air Board should remain unchanged, *i.e.*, that it should continue to discuss matters of air policy and to constitute a medium for the interchange of ideas on air problems between the two Services and related bodies. Arrangements as to *personnel*, training and operations should remain in the province of the Admiralty and War Office.

The suggestion that the supply branches of the two Services should be amalgamated was not new. It had already come from the Ministry of Munitions, with the difference that the Ministry and not the Air Board was proposed as the supply authority. A memorandum on the subject had been submitted to Mr. Lloyd George, then Minister of Munitions, in May, 1916, by Mr. Weir (afterwards Lord Weir), then Director of Munitions in Scotland. The intimate connection between supply and policy was already beginning to make itself felt and with it the necessity for placing supply on a more satisfactory basis. The proposal had already been discussed by Mr. Weir with the Director-General of Military Aeronautics. The general argument in its favour was thus expressed in the memorandum:—

> "To facilitate rapid action it appears better to take the fullest advantage of present organizations rather than to create entirely new and independent ones, especially on a question bound up with conditions of industry. . . . It is submitted that the Ministry of Munitions undoubtedly possesses more of the qualifications and powers necessary for an ideal War Supply Department than can be possessed or granted by law to any new department still to be created."

Mr. Weir proposed that design should be taken over as well as supply, and placed under the charge of a Superintendent of Design.[1]

The immediate cause for the Ministry's putting forward this suggestion was a demand by the Air Board in July, 1916, for absolute priority for steel, machine tools and labour for aeronautical work.[2] The proposal was rejected both by the naval and military authorities and by the Air Board, but the Admiralty was equally averse to the extension of the powers of the Air Board in the manner proposed. There were various reasons why the taking over of naval aircraft supply would prove a more difficult undertaking than the transfer of military supply. In the first place the Ministry of Munitions had been established as the recognised supply department of the War Office, and the officials at the Admiralty entertained serious doubts whether, as a result of amalgamation under the Ministry of

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[1] HIST. REC./R/1960/4. [2] C.R. 4447.

Munitions, naval requirements would receive the effective treatment accorded to the War Office. The normal system of supply in operation at the Admiralty, which applied to aircraft as well as to other material, rendered difficult any transfer of staff, and by the pooling of technical ability the Navy might well be the loser. Moreover, the Admiralty had always viewed with apprehension any divided relations between the user and the producer. The military authorities favoured the Air Board scheme for supply, and a general objection to the rival scheme was that the difficulties encompassing the supply of aeroplanes were unique and outside the experience of the Ministry. Against this, it had been found in the case of other munitions that the difficulties were not insuperable, while the problem of obtaining production of an article of changing specification was one with which the Ministry was only too familiar.

The Government recognised the importance of retaining an Air Board to carry out the advisory functions allotted to it in May, 1916, and more especially to allocate the aerial resources of the country between the Admiralty and War Office, but at the same time the advantages of vesting the whole authority for supply in the Ministry of Munitions were too obvious to be ignored. The Government was in fact primarily guided by the facts of the manufacturing situation. The vital necessity for an increased output of aircraft, and for the elimination of competition for materials and accessories between the Royal Naval Air Service and the Royal Flying Corps were two considerations of the first importance in arriving at a decision. The policy of standardisation, as will appear below,[2] could only be made possible by the co-ordination of requirements. The resources of the country in material and labour were severely taxed by the war. The Ministry of Munitions had found it necessary to control these resources, thus bringing the two Services into inevitable conflict with the Ministry as well as with each other, more especially with regard to machine tools and petrol engines, which the Ministry required for transport. All questions of shortage resolved themselves into questions of priority, and it was far easier for a single Department to adjust claims among its branches than for separate Departments to reconcile their conflicting claims. Lord Curzon's main point was the necessity for strengthening the powers of the Air Board, and thus leading to the creation of an Air Ministry, but the needs of the moment brought supply into greater prominence than any purely administrative problem, and supply was, in the existing emergency, the province which the Air Board was least competent to handle.

The Government decided in November, 1916, that, to facilitate the relations and to secure uniformity of procedure between the Air Board, Admiralty and War Office, a Fifth Sea Lord should be added to the Board of Admiralty with authority, as far as possible,

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[1] Hist. Rec./H/263.91/1.

[2] See below, p. 156.

corresponding to that of the Director-General of Military Aeronautics, and that a representative of the Ministry of Munitions should be added to the Air Board. The suggested distribution of authority between the authorities concerned was as follows :—[1]

"(a) The Admiralty and War Office will concert their respective aerial policies in consultation with the Air Board.

"(b) The Admiralty and War Office will formulate the programmes of aerial production required for the fulfilment of the approved policy and will submit these programmes to the Air Board.

"(c) The Air Board will decide as to the extent to which it is possible to approve the Departmental programmes, having regard to the possible rate of production, the needs of the other Departments and the respective urgency of the demands.

"(d) The Air Board will place the order with the Ministry of Munitions.

"(e) The design of the machines and commodities ordered will be undertaken by the Ministry of Munitions, working in the closest possible association with the Department for whom the order is placed.

"(f) The Ministry of Munitions will give every facility for direct communication on all matters of detail between the representatives of the Admiralty Air Department, and the Department of the Director-General of Military Aeronautics respectively, and the actual manufacturers.

"(g) Any of the Departments represented on the Air Board, and the Air Board itself, will have the right of appeal to the War Committee in case of dispute."

On the three points, viz. (1) the appointment of a Fifth Sea Lord, (2) an Air Board with powers to allocate resources, and (3) the transference of supply to the Ministry of Munitions, the Government had taken a definite decision, but points for further consideration were the position of design, the control of the Royal Aircraft Factory at Farnborough and the co-ordination of research. A change of Government took place in December, but on 22 December the new Government approved the decision of its predecessor, in spite of renewed protests from the Admiralty and Air Board. They further decided that the details of the new arrangement should be worked out by the Air Board, the Admiralty and the War Office, in consultation with the Ministry of Munitions, and that the final inspection and approval of aircraft should still be in the hands of the Admiralty and War Office.

The proposal that the design and research branches of the Services should be amalgamated under the Ministry of Munitions was not carried out at this time. It was agreed that though centralization

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[1] HIST. REC./R/1960/20.

was necessary, aircraft stood in a special category, since, in so novel an arm, the development of pattern depended to an extraordinary degree upon the experience of the users and was peculiarly closely connected with strategy. The Air Board was, therefore, made responsible for experimental work and approval of design of aircraft, the numbers to be ordered and their allocation between the Services, while the Ministry of Munitions undertook production and inspection during manufacture, handing over the stores when completed to the Air Service for which they were destined. At this period, a substantial proportion of the engines and aircraft were of Government designs, prepared at the Royal Aircraft Factory, Farnborough. This establishment was taken over by the Ministry of Munitions, to which it provided first-hand advice on the technical aspects of manufacture.

The new Air Board was constituted on these lines on 6 February, 1917, consisting, in addition to the President, of a Parliamentary Secretary, the Director of Naval Air Services as Fifth Sea Lord, the Director-General of Military Aeronautics, the Controller of Aeronautical Supplies and the Controller of the Petrol Engine Department, the last two being officers of the Ministry of Munitions. A technical department of the Air Board was formed to deal with all matters of research, invention and design. An Air Inventions Committee was set up by Lord Cowdray, who had succeeded Lord Curzon as President of the Air Board in January, 1917, to examine inventions relating to heavier-than-air craft, and a Committee on Civil Aviation, with Lord Northcliffe as chairman, was also constituted.

To produce the best results from such a division of functions, it was necessary to secure the closest liaison between the users, *i.e.*, the Royal Naval Air Service and the Royal Flying Corps, the designers and controllers of policy, *i.e.*, the Air Board, and the producers and inspectors, *i.e.*, the Ministry of Munitions. In order to promote this it was decided that the Air Board should remove from Carlton House Terrace to a building capable of containing not only themselves but the headquarters of the Royal Naval Air Service and the Royal Flying Corps, and the Department of the Ministry of Munitions that was to undertake the supply of aircraft. The Hotel Cecil was selected for the purpose, and it was occupied by the various departments by January, 1917.

The duties and composition of the reconstituted Air Board are of importance as indicating the general trend of lay opinion at the beginning of 1917. It was recognised that a combined Service under an Air Ministry might have been an ideal arrangement, but the time seemed inopportune for a reorganisation which would have been bound to cause a certain dislocation in the Air Services, since these were daily becoming more vital to both naval and military operations. The opposition of the Admiralty to such a scheme was deep rooted in the essential differences between the nature and use of aircraft for the two services, and made an easy settlement of the difficult problems

involved seem unlikely. The Germans were making a determined effort—not without some success—to establish ascendancy in the air. They had recently produced two or three very fast types of fighting machine which had eclipsed those used in many of the British fighting squadrons. The recent successes on the Somme front had been largely due to the predominant position established by the British aircraft, whereby the Germans had been effectively prevented from overlooking our front lines.[1] To risk losing this predominance for any cause, jeopardized the success of any future offensive on a large scale. The demands on the Air Services for anti-submarine work and home defence were equally urgent, for the "ruthless" submarine campaign was to begin on 1 February, 1917, and the success of aeroplanes in dealing with repeated Zeppelin raids throughout 1916 had entailed new demands on the Royal Flying Corps.

Up till this time the adoption of any definite air policy by the home authorities was out of the question. The ever growing series of activities to which aircraft was successfully applied, resulted in continuously growing demands on the limited manufacturing resources of the country for purely naval or military purposes, and the building up of a reserve for an independent aerial campaign against Germany was impossible. The machines and pilots of the Royal Flying Corps were exclusively occupied in artillery co-operation, aerial fighting, ground target work, tactical bombing of enemy communications and transport at short range, photographic and reconnaissance work, duties all definitely associated with military operations, while those of the Royal Naval Air Service were mainly utilized in work equally definitely associated with naval operations. Only one course was open to the home authorities, and that was to give the two Services all the aircraft which they so unquestionably needed. It thus came about that during the first few months of the life of the new Air Board no questions of policy arose. By July, 1917, however, the Ministry of Munitions had the supply position well in hand. It appeared that by the end of the year aircraft would be coming forward in large quantities, but, as Sir William Weir pointed out, it was perfectly clear that unless a properly constituted Air General Staff was appointed under the Air Board or an Air Ministry, aviation output, however large, would continue to be absorbed by the two Services, and though this use for aircraft was entirely justifiable, it was conceivably not the most effective use to which it could be put. The sobering experience of three years of war raised the question as to how far decisive military victory was possible. A deadlock appeared to have been reached both in the naval and military theatres, and it seemed conceivable that a sustained air offensive might be more powerful than any other factor in undermining the *morale* of the enemy and disposing him towards a reasonable peace.

The settlement of this question became imperative when in September, 1917, British air ascendancy was once more seriously threatened, and General Trenchard, General Officer Commanding the

[1] D.M.R.S. 467.

Royal Flying Corps Expeditionary Force, while seeking approval for a programme involving a total establishment of 200 squadrons by the end of 1918, pressed for an acceleration of the already approved programme of 86 squadrons, in order that his position might be improved before the winter, his great fear being that ascendancy once lost could never be regained. It was recognised that any acceleration in the aircraft programme already arranged for was bound to entail a curtailment in the programmes of other departments, but as there was reason to believe that the Germans intended extending their aerial programme at the expense of guns and ammunition, some similar step on the part of the British Government seemed essential. The adverse effect of the absence of definite policy upon supply had already been felt, and these effects were bound to become more marked as programmes increased, and the possible consequences of mis-directed effort became more serious. These considerations necessitated a reconsideration and speedy decision of the whole problem.

To enable the Air Board to formulate a national policy it seemed clear that it must be provided with its own war staff of experts. Under the existing conditions the expert members of the Board were representatives of the two Services, and naturally their first consideration was the interest of their own Service. No policy adopted by the President under these circumstances could have the same weight as one based on free and disinterested expert advice. Under its existing constitution[1] the Air Board would cease to exist twelve-months after the conclusion of the war, and under such conditions it could not obtain a war staff possessing the necessary technical knowledge which would enable it to hold its own with the naval and military staffs, since no highly placed and skilled officer would be justified in taking a temporary position which might place him in antagonism with his present Service, to which he might later have to return. A permanent Air Board or an Air Ministry thus became essential. The question still remained whether the Royal Naval Air Service and Royal Flying Corps should continue as separate Services with a "Surplus Aircraft Fleet" under the control of the Air Board, or whether a union of the two branches should take place. There were reasons, however, which made unity of administration of the Air Force much to be desired. Under the existing scheme the Army Council and the Admiralty supplied pilots and *personnel*, the Air Board and Ministry of Munitions the machines and equipment, while the War Office Department of Fortifications and Works supplied aerodromes. Any failure on the part of either of these authorities made the efforts of the others unavailing. There was, moreover, need for a specialized medical service, many of the physical disabilities to which pilots were liable being peculiar to the Service and necessitating special research.[2] With the expansion of the Air Services the definite allocation of duties between them became of more importance. The practice adopted by the Royal Naval Air Service during 1916 of undertaking land raids to protect the Grand Fleet against Zeppelins had

[1] *New Ministries and Secretaries Act*, 1916.
[2] *Parliamentary Debates*, 1917 (*H. of C.*), XCIX, 129.

given rise to complications with the military command,[1] and it seemed advisable that the activities of the Naval Air Service should be confined to fleet and anti-submarine operations. Six months' co-operation by officers of the two Services with the Air Board and the Ministry of Munitions at the Hotel Cecil had automatically solved some of the difficulties which had seemed so formidable at the end of 1916, and a union of the Services was now possible without any risk of dislocation of vital services.

The Government decided in August, 1917, in favour of the principle of uniting the Services and providing a special branch for the systematic raiding of German munition centres, and an Air Organization Committee was appointed under the chairmanship of General Smuts to work out the details for an Air Ministry, Air Council and combined Air Force. General Smuts at once recognised that if any policy of long-distance bombing was to be effective during 1918, steps must immediately be taken to provide the necessary *matériel* and *personnel*. An Air Policy Committee was appointed on 16 October, 1917, to advise the Government during the interval before the Ministry could come into being. The immediate duty of the committee was to determine the objectives of the raids and the forces to be employed in order that arrangements might be made for supply. The Air Council was set up by Order in Council on 21 December, 1917. Lord Rothermere became Secretary of State for Air in January, 1918, and the Air Board was reconstituted as an Air Ministry. The Air Council was composed as follows :—

> Secretary of State (President), Sir David Henderson (Vice-President), Chief of the Air Staff, Deputy-Chief of Air Staff, Master-General of Personnel, Controller-General of Equipment, Director-General of Aircraft Production, Administrator of Works and Buildings, Parliamentary Under-Secretary of State.

The relations between the Air Ministry and the Ministry of Munitions thus became technically the same as those between the War Office and Ministry of Munitions, with the very important difference that the Director-General of Aircraft Production was a member of the Air Council and consequently in close touch, not only with the Controller-General of Equipment, but also with the Chief of Staff and Secretary of State. The maintenance of the closest possible relations between producers and users of aircraft was thus assured. The Royal Air Force came into existence on 1 April, 1918. Shortly afterwards, Lord Rothermere resigned and Lord Weir was appointed Air Minister on 1 May.

This appointment was peculiarly appropriate, in that long-range bombing was one of the chief problems with which the Ministry had to deal, and Lord Weir (then Sir William Weir) had since June, 1917,

[1] Memorandum on Long-Range Bombing Operations by Aircraft, 9 November, 1916. (HIST. REC./R/1960/20.)

been pressing for its consideration. It was, indeed, due to his efforts that the building of any large bombing machines for the Royal Flying Corps was embarked on prior to January, 1918. The question of the division of responsibility between the Army and Navy for this form of warfare had arisen early in 1916. Both Services claimed the duty of carrying out raids from French or Belgian territory with the object of destroying Zeppelins in their sheds. Any pre-war plans for such operations had been based on the assumption that places near the Belgian frontier would be available as bases,[1] and raids on the Zeppelin sheds at Cologne and Dusseldorf had been made by the Royal Naval Air Service from Antwerp early in the war, as a means of defending the home country from attack. The advance of the German line westward had rendered impossible any further raids during 1915, as it put the objective outside the range of the machines of that date. The only Zeppelin shed which could have been raided by the Royal Flying Corps was near Namur, but their offers to bomb it were rejected by the Commander-in-Chief. He could not spare any machines or pilots for such work, and grudged the Royal Naval Air Service any machines which they could collect for the purpose. The military authorities considered that too much was claimed for the effects of bombing, when it was stated that "the end of the war would be brought about by the effective bombing of open towns," and moreover they objected to the bombing of open towns on principle. They maintained that military policy, in aerial as in other respects, must be based on the principle that a successful end of the war could be brought about only by decisive victory over the enemy's forces in the field. For this purpose they claimed every available machine and engine. This scepticism as to the value of bombing was probably well founded, in view of the small power of the bombing machines available for the Royal Flying Corps in 1916. The naval authorities had larger machines and higher powered engines, and they maintained that it was the duty of the Royal Naval Air Service to do anything which would interfere with the efficiency of the German fleet. The first object of the Service should, therefore, be to destroy in their sheds the Zeppelins, which were the eyes of the German fleet, and the second to attack the factories which provided for the replacement of guns, etc., with a view either to inflicting actual damage upon them or to reducing their output by compelling the extinction of light, etc. Moreover, they held that bombing operations were of the highest value, in that they withdrew enemy machines from the front, and diverted them to the protection of German towns exposed to aerial attack, and that, by striking at the heart of Germany, they would have an effect on many of our problems—the Zeppelin attacks, submarine warfare, and the supply of guns and searchlights. In the autumn of 1916, the Admiralty, accordingly, made arrangements with the French authorities to carry on independent bombing operations against enemy territory from a base at Luxeuil, near Belfort. In October, it was proposed that a force

[1] Minutes of Committee on the Administration and Command of Royal Flying Corps, 14th Day, 5th July, 1916.

of at least 200 machines should be kept in France for the purpose, and that orders for engines for the use of these machines should be placed in France. In November, 1916, there were already 54 naval aeroplanes assembled at Luxeuil ready to begin operations. The military authorities raised most emphatic objections, maintaining that, even if the diversion of machines, which they so badly needed at the front, was justified, the operations should be under the control of the Commander-in-Chief, and not carried out independently of his strategical plans. The Air Board upheld this view and the question lapsed for the time being. When it was again brought forward, in 1917, the military authorities were still unenthusiastic about long-range bombing. They still wanted all available bombing machines for their own form of bombing, for which extra speed was to be preferred to extra weight-carrying capacity, and in any event they thought that any given weight of bombs was more likely to reach its destination in smaller machines. Naval experience was opposed to this view, for the Handley Page bombing machines had already been in use in the Navy and not one had been lost on account of its low speed. One Handley Page, with a crew of three, carried six times the weight of bombs carried by a D.H.4, and 6 D.H.4's would require a *personnel* of twelve.

In October, 1917, the Germans started bombing Dunkirk with a new type of four-engine armoured battleplane, upon which fire from machine guns had no effect. The importance of heavy bombing was thus realised and in November Sir Douglas Haig recommended the formation of 66 squadrons of long-distance bombing machines for operations against Germany. For night-bombing purposes he required machines giving a better performance than the Handley Page with Rolls-Royce Eagle engines.

Had it not been for Sir William Weir's insistence upon ordering these machines, while still unsupported by military opinion, they would hardly have been forthcoming before the Armistice. In July, 1917, he had persuaded the Air Board to order 700 machines of the D.H.9 type for day bombing, and in September 400 Handley Pages for night bombing, on the understanding that their production was not to interfere with that of the machines demanded by the Services. His contention was that, though little experience existed as to day or night bombing and the machines were at a very early stage of development, the Board might be severely criticised if, when there was a possibility of getting heavy bombers, however inefficient, without interfering with the provision of high-speed bombers, they had failed to provide any at all. The production of the large machines was such a lengthy process that long preparation was essential, and, as it turned out, technical delays were so great that neither type was in production until the spring of 1918.

The new Air Minister lost no time in submitting a scheme which, while providing for the adequate performance of the necessary military and naval duties of the Royal Air Force, should also provide for the formation of a special establishment devoted to long-range

bombing. He recognised that long-range bombing machines, utilised by day and night against munitions centres or military targets outside the range of military machines, involved operations of a purely aerial character, requiring for their conception and execution a large measure of freedom and independence from other military schemes. He therefore proposed that each Air Force Group should have a minimum permanent establishment, the strength of which should not be reduced without reference to the War Cabinet, and an agreed development programme, while any additional resources should be at the disposal of the Air Ministry, as equipment for an independent Air Force available either for allocation to the Army or Navy for special operations or for the carrying out of a scheme for the continuous and progressively increasing bombing of German munitions centres.

The independent Air Force was constituted on 8 June, 1918, its Chief, General Trenchard, being directly under the Air Ministry. It comprised four squadrons, and arrangements were made to bring the establishment up to at least 24 squadrons by the end of October. The machines to be provided ensured night and day bombing over a fairly wide range of Rhine towns, and it was hoped that a small force would be available for bombing more distant objectives such as Essen and other Westphalian towns. Serious shortage in the supply of high-powered engines curtailed the programme during the summer of 1918, but the limited amount of raiding which took place had a powerful effect on the enemy. A later development, hoped for by the spring of 1919, was the provision of powerful day-bombing machines with a fighting escort, which would force the Germans to provide fighting machines and anti-aircraft guns for home defence. Special bombs weighing 1,700 lb. were prepared to be carried by these giant bombers, but the Armistice was signed before any of these were used.

II. Development of Uses and Types of Aircraft.

(*a*) Growth of Functions of Aircraft.[1]

The chief function of the military aeroplane recognised before the war was reconnaissance. The information gained prior to and during the retreat from Mons, in 1914, was of the greatest possible assistance to the Allied armies, and attention was at once directed to the development of this use of aircraft. With the advent of trench warfare it became particularly important to supplement reconnaissance reports by full information as to the position of enemy trenches and the location of his batteries. The first successful aerial photograph was taken of the village of Neuve Chapelle in November, 1914, the photographic section at that time consisting of two officers and three other ranks, their outfit comprising two cameras and a portable box of developing chemicals. Early in 1915, a specially-designed aerial camera was evolved, and from this time photography developed

[1] This Section has been compiled from the following papers:—*Some Developments in Aircraft Design and Application during the War* (Lord Weir); and *A Short History of the Royal Air Force: British Air Effort During the War.* (1919, Cmd. 100).

rapidly. Artillery co-operation was another function of aircraft, the usefulness of which became recognised directly the military situation became stabilised on the Aisne, and this function increased in importance as artillery barrage was developed on scientific lines. The early methods of signalling were of a primitive type, since wireless telegraphy as applied to aircraft was only in its infancy. With the original Expeditionary Force, there was only one machine fitted with wireless, and signals were conveyed by evolutions of the machine over the target, and later by signal lamps or smoke balls fired from Véry pistols. As time went on every battery was equipped with a wireless receiving station, and the problem of fitting wireless apparatus to an aeroplane was satisfactorily solved.

Very early in the war the prevention of enemy reconnaissance became a paramount necessity, and fighting machines were developed. Air combats were of frequent occurrence from the earliest days of the war, but it was not until after a year of war that fighting in the air became a recognised feature in operations. Since then it steadily increased in intensity. From the single combats of the early days of the war there developed battles between patrols and between large formations of machines, as many as 70 or 80 being engaged at one time. The class of machine supplied for this purpose was principally the single-seater fighter, but from the original reconnaissance machines were evolved during 1916 armed two-seater fighters, which were at first intended merely to defend themselves against attack when on reconnaissance, but soon developed, owing to the characteristics of the British pilot, into offensive fighting machines.

From the earliest days of the war, small bombs had been carried by the Royal Flying Corps, whenever possible, for use against any likely target, and the bombing of Zeppelin sheds was one of the recognised duties of the Royal Naval Air Service from the beginning, but it was comparatively late in the war before systematic bombing was adopted. When organised attacks first developed, the original reconnaissance type was used, but as soon as the special requirements of this work were understood, specially-designed aeroplanes appeared. The early bombing machines were capable only of short raids, and their slow speed made them an easy prey to enemy scouts. As bombing developed, machines were sub-divided according to their particular function, as day bombers, short and long distance, and night bombers, short and long distance.

The ground fighting machine was a comparatively late development. For a long time it was believed that the risk attendant on low altitude flight was too great to justify the use of pilots and aeroplanes in this manner, but a series of remarkable escapes by pilots who were forced to return across the lines at low altitudes proved that the danger had been overestimated, and immediate development of this mode of fighting took place. It was of great value in breaking up dense infantry formations during the German offensive of March, 1918, but our casualties were heavy, since no special armour had at that time

been evolved. The provision of a suitable armoured aeroplane was taken in hand. It was not, however, produced in time to come into active service.

Little night flying was done until the end of 1915. At that time the enemy made several airship raids over England, and early in 1916 steps were taken to deal with Zeppelins by aeroplane attack at night.

Aeroplane armament at the outbreak of war was practically non-existent. In the early days of the war machines were either entirely unarmed or the pilot carried a revolver, service rifle or Winchester repeater. The rapid development of aerial fighting necessitated the invention of a special synchronising gear enabling machine guns to be fired through the airscrew, and of special ammunition such as incendiary, tracer and armour-piercing bullets. Aerial bombs were at a rudimentary stage of development in August, 1914. Pilots sometimes carried a few small bombs to be dropped by hand as opportunity offered. The bombs were fitted in various ingenious but crude ways, *e.g.*, with pieces of string and cutting knives, and the attacks were made by diving low and dropping the bombs as accurately as possible.

(*b*) Progress of Invention.[1]

The outbreak of war found aeronautical science based upon a solid groundwork, owing to the amount of research carried out before the war. By much patient work and experiment, undertaken by private enterprise and at the National Physical Laboratory and the Royal Aircraft Factory, unproductive fields of research had been eliminated and the lines along which future development should be sought were clearly defined. The method of supplying propulsive power by means of an engine and propeller was firmly established as the only immediately practicable means of securing flight. The problem of inherent stability had been to a large extent solved, for both the R.E.1, an experimental reconnaissance machine, and the B.E. 2 c., built before the war to Royal Aircraft Factory design, had complete inherent stability, and paved the way for the design of machines with any requisite margin of stability. The value of the cambered surface for wing sections had been clearly demonstrated, and by exhaustive research in the wind channel great advances had been made towards the evolution of the most effective form of camber. The aeroplanes of that time were built on sound lines, but their performance was poor and their structure not adapted either in design or strength for the manœuvres required under war conditions. The increased performance of the modern aeroplane has been largely due to refinements in the design of pre-war types, and to progress in engine design, for maximum speed and climb are achieved by a reduction of gross weight carried per horse power. At the beginning of the war, loadings were about 23 lb. per h.p., and at the close in the neighbourhood of 7 lb. per h.p.

[1] This Section has been compiled from a paper by Lord Weir: *Some Developments in Aircraft Design and Application during the War.*

Stability in modern aeroplanes is obtained by so adjusting the disposition of the main planes and controlling surfaces that the machine has inherent stability. Longitudinal or fore-and-aft stability is obtained by means of the tail plane, the size of which depends upon the position of the centre of gravity of the machine with respect to the main planes. Lateral stability is obtained by giving the main planes a dihedral angle, by setting the spars at a small angle with the horizontal. Directional stability is obtained by the proper disposition and dimensions of the fins and rudders. An impression was prevalent in the early years of the war that a stable aeroplane must necessarily be heavy upon its controls, and since quick manœuvrability was essential for fighting scouts, the aim of designers, encouraged by fighting pilots was to obtain maximum controllability and handiness with indifference to stability. It was gradually realised that this was a mistaken view and that the poor manœuvrability of the older stable machines was due to defective design of the controlling surfaces. Later research on the subject produced data to guide the design of machines which were both inherently stable and manœuvrable, and the prejudices against stability quickly disappeared. "A good example of the advantage of inherent stability is afforded by Captain Ball's wonderful return to our lines on his stable S.E. 5 machine, after his controls had been almost completely shot away. The aeroplane practically flew itself back, and with only half his normal elevator control he was able to make a safe landing on the aerodrome. Such a feat would have been out of the question on an unstable machine."[1] For bombing and long-distance work stability is very essential, as it relieves the pilot of fatigue and facilitates the maintenance of his course, and his sighting for bomb dropping. German aeroplanes did not compare favourably with ours in this respect, and it is probable that the heavy proportion of their bombers which crashed on returning from their raids was due to the lack of stability and controllability.[2]

For war aeroplanes, the reduction of weight while maintaining the necessary strength is a factor of great importance. In 1914, little was known about the magnitude of forces which might occur in flight, and the strength of an aeroplane was determined by more or less arbitrary rules. It was only by careful examination and analysis of accidents that sufficient data were obtained to guard against certain forms of failure, and the advance of knowledge on this subject during the war has been one of the principal factors in eliminating accidents due to faulty structure of the aeroplane, and in reducing the weight of the aeroplane. It is now possible to design a machine which will not break in the air except under certain conditions against which the pilot can be warned.

The outbreak of war was at once followed by demands for improved performances in every respect. Increased lifting power, speed, rate of climb, manœuvrability and higher ceiling (the maximum height to which the machine can climb) were of immediate importance,

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[1] *Some Developments in Aircraft Design and Application during the War*, p. 15.
[2] *Ibid.*, p. 16.

and as these requirements are to a certain extent mutually exclusive, much experiment was necessary to produce a satisfactory compromise. It was not long before machines were being classified according to the duties required of them, so that attention could be concentrated upon the particular requirement for the different types. The original war reconnaissance machine was not intended to carry any military load except the crew, but directly war broke out the equipment required began to increase and reconnaissance aeroplanes were overloaded with equipment of all descriptions. Pilots, wishing to be prepared for any emergency, took guns, bombs, cameras, wireless equipment, attaching them to any available part of the machine. The increased weight and head resistance produced a serious reduction in performance, and quite early in the war an order had to be issued to prevent pilots from endangering their lives in this way. It was not until the latter part of 1916 that machines were produced capable of carrying all the equipment required while maintaining the requisite standard of performance. The increased performance was due, not only to the use of more powerful engines, but to the fact that the aeroplanes were designed to carry the equipment as far as possible internally, thus avoiding all unnecessary resistance.

For both fighting and reconnaissance machines a rapid rate of climb and high ceiling became of greater importance as anti-aircraft fire improved in accuracy. An average ceiling at the outbreak of war was 7,000 ft., and aeroplanes could do their work with reasonable safety at 3,000 ft. ; in fact, military training before the war had proceeded on the hypothesis that this would be the height at which reconnaissance and photography would be carried out. At the end of the war shooting at 20,000 ft. was unpleasantly accurate, and ceilings had increased to 25,000 ft. Rapid climbing, as well as being the most valuable, is one of the most difficult qualities to obtain. Practically all other considerations are opposed to it, such as high superficial loading, direct drive engines, high speed and long range, and during the first years of the war the difficulty was increased by constant addition to the number of accessories required for increasing military duties. For all types of machine a low air resistance is a valuable quality. Much research has been devoted to this problem, and though this has been on the general lines of application of what was already known before the war, great advances have been made by evolving better wing sections and by the use of wires of streamline section wherever possible. Great improvements have also been made by studying the best shape for a fuselage or body and by suitably protecting the pilot and accessories. For high-speed machines, both bombers and fighters, the principal requisites are wing sections of high efficiency, high superficial loading combined with powerful engines and bodies of carefully stream-lined shape. Attention to these points secured machines which were very fast in the air and which could be landed easily after their load of bombs had been dropped, but whose heavy wing loading made a forced landing very dangerous.

During the war, experiments were made with monoplanes, biplanes, triplanes and quadroplanes, and the first three of these types have been built on a production scale. Each has its advantages for certain purposes. Broadly speaking, the comparative advantages are as follows.[1] In comparison with the biplane, the monoplane is 5 per cent. more efficient as a weight carrier per square foot, and can be made to afford a better fighting view. On the other hand, it is weaker and less manœuvrable for the same weight of structure. The triplane as compared with the biplane is 5 per cent. less efficient, but is more manœuvrable, and affords opportunities for a deeper and therefore stronger main girder, which gives it an advantage for the larger sizes. It is, however, more difficult and expensive to produce. A successful triplane fighter has been produced only to be outclassed by the more successful biplane. The very small span contributed handiness to the machine, and a good view ahead was obtained by placing the pilot so that his eye was on the line of the centre plane. The British practice was, however, the selection of the biplane as the soundest type for all ordinary work.

Fuselage construction proceeded on much the same lines throughout the war. Three methods were employed. The first and most usual consisted of four longerons, or fore-and-aft rails, braced by struts and diagonal wires in all four faces, the whole structure being covered with fabric. In the second method, bracing wires and fabric were replaced by three-ply wood, glued to the frame-work. The third, or monocoque, fuselage consisted of a single sheet of three-ply or veneer moulded to shape on formers. The first and third methods were used before August, 1914, and the second was used by the Germans in the early days of the war, and was afterwards adopted by British manufacturers. The chief advantage of the monocoque fuselage, from the military point of view, is its invulnerability to casual bullets. A pierced longeron might cause the complete collapse of the structure, but a monocoque will stand any number of bullet holes.

Airscrews used for aircraft have been developed from marine screws. The great variations in the speed of the aircraft, in the horse-power of the engine and in the rate of revolution of the airscrew necessitated much research on design, and a method was evolved by which airscrews suitable for all classes of aircraft with very high efficiency could be produced with great accuracy. Little success was obtained during the war with airscrews of metal construction, and wooden propellers of mahogany and walnut were used throughout. Material of the highest class must be used, for at the speed of modern aeroplanes the stresses set up in the blades are very heavy.

Various methods of protecting the airscrew from weather have been adopted. Lacquering was tried, but though it gave an excellent surface finish it was found that the surface became badly pitted under the stress of rain and, in the case of seaplane airscrews, of spray and sand, and it was eventually relinquished in favour of fabric covering.

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[1] *Some Developments of Aircraft Design and Application during the War*, p. 14.

As the wood used was green and had to be kiln-dried before use, fabric covering was resorted to throughout the Services. It was originally adopted for airships, and with the object of hermetically sealing all the joints, so that the airscrews were not affected by change of temperature. If an airship propeller were hit or damaged in any way liable to cause the wood to splinter, fabric covering was a means of preventing splinters from flying into the gasbag. For seaplanes, fabricing and metal tipping were used from the very early days, though the present-day seaplane airscrew has been modified considerably as regards metal tipping. In 1915 the seaplane airscrew was metal-sheathed one-third of its diameter, but this has since been superseded by a brass beading. It has been found by experiment that the leading edge of the tip is the only portion which it is necessary to protect in this way. All low-chassis machines now have their airscrews beaded with metal as a protection against long grass, stones, etc.

Machines are classified as pushers or tractors according as the airscrew is placed behind or in front of the wings. In machines of the pusher type, the body or fuselage is replaced by a nacelle or cabin, containing the crew and engine, the tail unit being supported by girders. The observer can be placed in the front of the nacelle, thus obtaining a good view ahead and a wide field of fire in a fighting machine.

Multi-engine machines have been made with both tractor and pusher airscrews. The question of multiple engine aeroplanes was considered at an early period of the war, and the conclusion reached in 1915 was that the advantage to be gained in the way of better aero-dynamical performance was probably small,[1] while the multiplication of engines made the machine more vulnerable. Later, however, the development of long-range bombing necessitated aeroplanes and seaplanes of such size as to outstrip the possibility of any one engine, and at the end of the war machines with two, three, four and six engines were in service or being built.

Aero-engine design on the outbreak of war had not reached the same stage of progress as the aeroplane, and throughout the war machines were designed to fit the types of engines which were available. The weight per horse-power ratio had been reduced just sufficiently to enable aeroplanes to fly. Beyond this, no special adaptation to aeroplane requirements had been attempted. The development of aircraft for warfare soon emphasised the importance of other factors. The extension of the range of operations and the losses due to engine failure raised insistent demands for greater reliability, while the necessity for easier maintenance called for engines of greater accessibility.

The Germans realised at an early stage the importance of high-powered engines, and they concentrated on the production of a simple type of an average weight per horse-power. British effort, on the other hand, was divided between numerous types, and at no time was any single type standardised. This policy resulted in difficulties

[1] *Advisory Committee for Aeronautics: Reports and Memoranda*, No. 216.

in production and, in the early years of the war, the engines were not so reliable as those of the enemy. Ultimately, however, we progressed much further than the Germans both as regards power and efficiency, for as the uses and types of machines multiplied, their inelastic engine policy became a drawback. The problem of producing an efficient aero-engine is a far more complicated one than the production of an automobile or stationary engine. The fact that it must be able to function in any position, and for a time at least, when completely inverted, involved new problems of lubrication, since it was practically impossible to carry oil in the crankcase. The shape of the engine requires careful consideration, since small head resistance, small moment of inertia and accessibility are most important factors. The wide range of temperature and pressure through which the machine must pass has an enormous effect upon carburation, lubrication, ignition and the system of cooling. Severe mechanical conditions are imposed on every part of the engine by the vibration due to high speed and lack of rigid support. The elimination as far as possible of risk of fire entailed much research on the ignition system, and the very severe centrifugal and inertia effects experienced in aerial fighting, coupled with the necessity under these conditions of immediate response to the throttle, necessitated careful design of the petrol supply system to ensure a constant and adequate supply of fuel. The violent and varying slip-stream from the propeller introduces difficulties with carburetter intake conditions, which are also affected by the diminishing density of the atmosphere as the machine climbs. Until the outbreak of war, aero-engines were fitted with elementary bloc tube or large-sized automobile carburetters. Early development was mostly in the direction of securing increased reliability and the prevention of fire risks. It was soon found that poor carburetter performance limited the ceiling of machines, and a great deal of work was done throughout the war at the Royal Aircraft Factory in connection with various types of altitude control, designed to give a constant air-to-petrol ratio at all altitudes. The earlier methods depended on a supply of extra air controlled by hand, but the later "vacuum control" types were automatic and depended on artificial pressure in the float chamber caused by suitable resistance to air flow in certain connecting pipes.[1]

Aero-engines have been developed along two lines, rotary and stationary, the former having cylinders and crankcase revolving round the fixed crankshaft, the propeller being attached directly to the crankcase, and the latter having fixed cylinders and crankcase, and a rotating crankshaft which drives the propeller. Rotary engines were in favour early in the war, owing to their small weight per horse-power. The small fast aeroplanes intended for short duration flights were usually fitted with rotary engines, since their relative wastefulness in lubricating oil was counterbalanced by their lightness. For scout machines or any machine requiring to take the air at a moment's notice and without loss of time, the rotary and radial air-cooled types of engines provided the essential conditions which no other type could.

[1] *Advisory Committee for Aeronautics ; I.C.E, Sub-Committee Reference No.* 4 ; HIST. REC./H/1960/2.

For this reason considerable attention was given throughout the war to the development of all engines of this nature. But since the maximum size compatible with efficiency was soon reached in this type, the stationary engine offered greater scope for development of higher power. It was found, moreover, that rotary engines were not suitable for corps reconnaissance machines, as it was difficult to throttle them to give the low speeds required for such work.

The earlier stationary engines were of six or eight cylinders arranged vertically or in two rows in V form. As the number of cylinders increased, the method of grouping them in V form or in three rows was generally adopted to reduce the length of the engine. An example of the stationary radial engines was in existence before the war in the Canton Unné (Salmson), but this type was not developed until comparatively late in the war when the arrangement was adopted in the A.B.C. Dragonfly engine.

For the first two years of the war, air-cooled engines were not developed to the same extent as water-cooled. Since the cooling surface of an air-cooled engine is less than that of a water-cooled, the cylinders of air-cooled engines presented a difficult problem, as they had to stand great heat and were liable to crack. They were, however, in many ways to be preferred for aviation purposes, as the water-cooling system accounted for a considerable amount of weight and also formed a vulnerable point in the engine. The research on air-cooled engines carried out at the Royal Aircraft Factory advanced this type of engine from a cloud of doubt to an atmosphere of reliability.

(c) DEVELOPMENT OF TYPES.[1]

The number of engines and aeroplanes evolved during the war was very large, and reference can here be made to a few only of the most successful types.

The three engines used by the Royal Flying Corps at the beginning of the war were of French design, the 80 h.p. Gnome, and 70 and 80 h.p. Renault. These continued in use until the end of 1915. There were no engines of British design available in August, 1914. The Royal Aircraft Factory had concentrated on the development of a 90 h.p. eight-cylinder air-cooled engine to replace the French engines, and one was actually running before the war, while the two firms of Napier and Rolls-Royce were encouraged to develop higher powered engines, the drawings for a 200 h.p. water-cooled engine, which had been in process of design by the Royal Aircraft Factory, being handed over to them. By the beginning of 1915, the 90 h.p. R.A.F. was being used on the B.E.2c. machine, and by the beginning of 1916, a 12-cylinder engine of 140 h.p. had been developed from it. Messrs. Napier, in collaboration with the Royal Aircraft Factory, produced the Napier R.A.F. engine of 200 h.p. which came into production late in 1916.

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[1] Based on *Some Developments in Aircraft Design and Application during the War: Short History of the Royal Air Force;* HIST. REC./H/1960/2.

Messrs. Beardmore had embarked on the production of the Austro-Daimler engine before the war, but, on account of various difficulties connected with the materials used, did not produce the engine in a reliable form for many months. This was a vertical stationary water-cooled engine of 120 h.p. with six cylinders in line.

The Royal Naval Air Service concentrated chiefly on the development of the Rolls-Royce and Sunbeam productions. In 1915, the Sunbeam Company produced an eight-cylinder Vee giving 150 h.p., and later a 225 h.p. water-cooled engine. About the middle of 1916, Messrs. Rolls-Royce produced the 75 h.p. Hawk, which was followed shortly by the 190 h.p. Falcon, eventually improved to give 275 h.p. The final outcome was the famous Eagle VIII, giving a horse-power of 375.

During the latter part of 1916 and throughout 1917, a great deal of work was done on the development of engines of high power. The 200 h.p. B.H.P. appeared early in 1917, and the Siddeley Puma, giving 230 h.p., was developed from it. The Sunbeam Arab engine was run towards the end of 1916, but was not in production until the end of 1917. The Maori, another Sunbeam engine, was in production early in 1918. The A.B.C. Dragonfly was under test in September, 1917, and was ordered in large quantities in the spring of 1918, but delay in production prevented it from being used in war service. The Bentley Rotary, a rotary engine of British design giving 230 h.p., was designed in 1916. In its final form, the B.R.2, it performed very useful service during 1918. The Atlantic engine appeared in May, 1918,[1] but did not come into service. The Atlantic Puma was a combination of this engine with Puma cylinder blocks, and came forward towards the end of 1918.

The Royal Flying Corps set out for France in August, 1914, with 66 aeroplanes of various types. They included B.E.2a's, B.E.2b's and Avros, of British design, and two types of French machines, Bleriots and Henri Farmans. It was found very early in the campaign that the B.E.'s and the Avro were the only machines which would withstand the weather. There were very few tents or shelters of any sort available, and the corps moved very rapidly during the retreat and the advance to the Aisne. The French machines began to sag directly they got wet.

The B.E. machine, a biplane design of the Royal Aircraft Factory, was in constant process of development. The B.E.2a and B.E.2b had been built before the war, and the B.E.2c had just appeared on the outbreak of war, and was the latest refinement of B.E.2a. and B.E.2b. B.E.2a had warped wings and was unstable. Its tankage was small, but it flew and climbed well compared with other machines of that date. B.E.2b was a modification of B.E.2a on lines desired by pilots. The observer was better protected, and it had a greater fuel capacity, but in point of performance it was no great improvement on B.E.2a. It was fitted with a 70 h.p. Renault, and for about a year was used in large numbers. In the B.E.2c the planes were staggered, *i.e.*,

[1] (Printed) *Weekly Report* No. 141, VII (11 May, 1918).

the upper projected over the lower, to give a better view of the ground. It had ailerons instead of warped wings, its tail was of different design and it was inherently stable. Its speed was improved at various times by altering the wing section and by using engines of higher power. It was fitted at different times with the 70 h.p. and 80 h.p. Renault, and 90 h.p. R.A.F.1a. This machine was used for all general purposes throughout 1915 and 1916. There was much controversy as to its value, but there can be no doubt that it enabled the Royal Flying Corps to carry on for many critical months before other machines became available. In numbers it formed from 70 to 80 per cent. of the total number of aeroplanes in use up to the middle of 1916. Its extreme stability made it unsuitable for quick manœuvring, and with the advent of aerial fighting in the middle of 1915, its unsuitability as a fighting machine brought it into disfavour.

The Avro machine fitted with the 80 h.p. Gnome was in use as a war machine for about a year. It was a useful machine, but neither pilot nor observer had full freedom of action and it was discarded when more convenient aeroplanes were forthcoming. It was used chiefly as a stop-gap pending the production of the B.E.2c, but it performed valuable service as a training machine up to the time of the Armistice, and is still the standard training machine. The 80 h.p. Gnome Sopwith Scout was bought by the Royal Flying Corps before the war. The Bristol Scout had been produced about the middle of 1914, and had been offered to the War Department, but at that time all available funds for machines of that type had been spent on the Sopwith. On the outbreak of war, two Bristol Scouts then under construction were ordered from the British and Colonial Company, and reached the Army in France about the end of August. They were good machines and were ordered in quantity and became available about November, 1914, the Martinsyde Scout following at the beginning of 1915. At that time the use of such machines was very limited and their suitability as fighters was not fully realised. One only was attached to certain squadrons, for the purpose of chasing German machines when they appeared over the lines. In the summer of 1915 they began to be very useful indeed, owing to the change in policy caused by the offensive tactics of the German Fokker fighting monoplane, armed with a machine-gun firing through the airscrew. The British pilots had formed the habit of making reconnaissances with single machines at regular times ; the machines were slow and the observers were in front, so that they became an easy prey to the Fokkers, which dived down in force behind them from great heights. From that time reconnaissance machines were sent out with a proper escort of fighting machines flying in formation, and the Fokker tactics were frustrated. This brought the fighting machines into greater prominence, and the Bristol Scout was fitted with the 80 h.p. Le Rhone to give increased speed. This machine replaced the Sopwith Scout at the beginning of 1915, because it gave a better view and was easier to fly. The Vickers Fighter, a pusher machine, was used at the front early in 1915, and by the end of 1915 it, with the B.E.2c

and Bristol Scout, were the British aeroplanes chiefly used in France, while the principal training machine was the Maurice Farman, supplemented by some Avro, B.E.2c, and Henri Farman planes.

The failure of the early attempts to devise a means of firing a machine gun through the airscrew brought the pusher machine into favour for fighting purposes, since the gunner, placed in front of such a machine, had an extensive field of fire. The F.E.2b, a two-seater, of Royal Aircraft Factory design, made its appearance towards the end of 1915. The D.H.2, a single-seater pusher, fitted with 100 h.p. Mono engine, appeared soon after, the first squadron detailed solely for fighting being equipped with these machines. Very valuable work was done by the F.E.2b and the D.H.2 machines against the Fokkers, particularly in the first half of 1916.

By the summer of 1916, synchronising gear to enable firing through the propeller had been produced, and the evolution of the tractor fighter followed very rapidly. The Sopwith two-seater, usually called the 1½ Strutter, and the Sopwith Pup, a small single-seater tractor scout with 80 h.p. Le Rhone engine, fitted with a Vickers gun with interrupter gear, made their appearance in the autumn of that year. In the former, which was at first fitted with the 110 h.p. Clerget rotary engine and later with the 130 h.p. Clerget, the pilot was placed close up to the engine, with a fine view ahead and downwards, and the observer was placed behind. Armed with a fixed Vickers gun firing through the airscrew, and a Lewis gun working on a Scarff mounting by means of which it could be trained in any direction by the observer, this aeroplane was a handy and effective weapon. The 1½ Strutter and the Sopwith Pup established standard types of fighting aeroplanes which have not since been departed from in principle. The advent of these tractor machines marked the decline of the pusher as a fighting machine. The F.E.8, a single-seater, appeared in numbers towards the end of 1916, and the last of this type was the F.E.2d, a two-seater with 250 h.p. Rolls-Royce engine.

When organised bombing was introduced in 1916 the B.E.2c was at first used for the purpose, though unsuited for it by its low speed and short range. It was gradually replaced, after July, 1916, by the B.E.2e, a faster machine fitted with dual control. The Martinsyde single-seater tractor bomber, with 120 h.p. Beardmore engine, made its appearance early in 1916, and was followed in the autumn by B.E.12, a single seater tractor bomber designed at the Royal Aircraft Factory. The F.E.2b, when displaced as a fighting machine, became a night bomber and was used until the end of the war.

Towards the end of 1916, the R.E.8, a tractor two-seater of official design fitted with 150 h.p. R.A.F. engine, was sent to France. In this aeroplane, the observer was placed behind, in accordance with the lessons which had been learnt as to the best relative positions of pilot and observer. It was armed with a Vickers synchronised gun and a Lewis gun, and eventually superseded the B.E.2c as the standard artillery reconnaissance machine. It was produced in very large numbers and on account of its stability was very suitable for its work.

The year 1917 was marked by very rapid development of specialised aeroplanes. The Bristol Fighter, a two-seater tractor with 250-h.p. Rolls-Royce engine, came into service in April, 1917. At the same time, the D.H.4 long distance reconnaissance and bombing machine appeared. Many different types of engine were fitted in this machine and its performance was uniformly good. The S.E.5 followed and was based on the Spad. It had 150-h.p. Hispano Suiza engine, and both it and S.E.5a, with the 200-h.p. Hispano Suiza, were fighting tractor scouts designed at the Royal Aircraft Factory. In them were embodied current aerodynamical research, and they were stable. The S.E.5a completely outclassed contemporary aeroplanes of similar type, and, armed with a fixed Vickers gun firing through the airscrew and a Lewis gun firing over the top plane, this aeroplane was a formidable craft. The Handley Page O.400 with twin 275-h.p. Rolls-Royce engines, a night bombing machine, early adopted by the Royal Naval Air Service, came into service with the Royal Flying Corps during 1917. The Sopwith Triplane also appeared in 1917, as a result of efforts made towards a fighter with increased view and manœuvrability. It had only one gun and the rate of fire was consequently slow. This machine was little used by the Royal Flying Corps. The Sopwith Camel, which was designed at the end of 1916, and came into production in 1917, had two synchronised Vickers guns. It was a biplane, and unstable but easily controllable. Enormous numbers of this type were produced during 1917 and 1918, with various engines of French and English design. The D.H.5 also appeared in 1917. It was a single-seater tractor fighter with 110-h.p. Le Rhone engine. It was characterised by a backward stagger, and though it had no great success as a fighter, it did excellent work for a short time as a ground fighter.

The year 1918 was marked by the development of the large bombing aeroplane. The day bombers D.H.9 and D.H.9a appeared in the spring, and aeroplanes were prepared to attack Berlin from a base in England. For this purpose, the Handley Page V.1500 was designed. It was an enlargement of the O.400 with four 375-h.p. Rolls-Royce engines, arranged in pairs on either side of the machine. Three days before the signing of the Armistice, two of these aeroplanes were standing ready and equipped to start for Berlin. Two other large bombing machines, the D.H.10a and Vickers Vimy, were in production at the time of the Armistice, but did not see service.

The Sopwith Salamander, the first aeroplane designed with special armour for ground fighting, was put into production in July, 1918,[1] but was not used in actual warfare.

The last fighting Scout to come into service was the Sopwith Snipe. It was built early in 1918, to take the B.R.2 engine of 230 h.p. and was used a great deal during the closing stages of the war. A Rolls-Royce engined Martynside Scout, the F.3, which had first appeared in 1917, was developed during that year. In its final form, Martynside F.4,

[1] *Aircraft Supply Committee*, 17 July, 1918. (HIST. REC./R/1960/19.)

with 275 h.p. Rolls-Royce engine, it was one of the best single-seater fighters available. It was in production at the time of the Armistice, but did not see service.

Thus, the process of evolution from the slow and inefficient types in use at the beginning of the war had produced single-seater tractors with speeds of over 130 miles per hour and ceilings of over 20,000 ft. actually used in warfare, while there were in production in November, 1918, similar aeroplanes with speeds exceeding 140 miles per hour, climbing to 15,000 ft. in 12 minutes, and with ceilings in the neighbourhood of 25,000 ft. Two-seater aeroplanes had developed into machines with speeds of 120 miles per hour capable of climbing 15,000 ft. in 20 minutes, armed with a Vickers gun trained by the motion of the aeroplane, and two Lewis guns fired by the observer. Lastly, there were the heavy bombers bristling with Lewis guns and carrying hundreds of pounds of bombs, and comparing in some cases not unfavourably as regards performance with the fast two-seaters.[1]

A great deal of experimental work on seaplanes was done during the early years of the war at the National Physical Laboratory. Seaplane construction has developed along two lines, the twin float seaplane and the boat seaplane or flying boat. The former has been developed from the aeroplane and resembles it in that it has a fuselage containing the crew and power plant, with floats of suitable shape attached to the undercarriage, while the boat-seaplane carries its engine, crew and armament in a hull slung below the wings. When riding at anchor, the flying boat floats upon this hull, which has a hydroplane stepped bottom to give the necessary lift to cause the craft to rise on the water and skim while acquiring flight speed. In addition to these two types of seaplane, the ship aeroplane has been developed and used extensively in naval warfare. The float seaplane developed along much the same lines as the aeroplane. The boat seaplanes proved very seaworthy and were able to remain on the surface of the water for long periods. They were eminently suitable for long reconnaissance and submarine bombing, and generally carried a crew of four. Ship's aeroplanes were specially designed to be flown from, and to alight upon the decks of, aeroplane carriers. They were adapted land machines, and their development was a marked feature of the later phases of the war, when they were provided with flotation gear to keep them afloat should they be compelled to come down on the water.

The seaplanes in existence on the outbreak of war were of very small carrying capacity, largely on account of the inadequacy of the engines available, the rotary Gnomes of 100 h.p. and 160 h.p. being the ones chiefly used. Just prior to the war, the folding seaplane and the torpedo-carrying seaplane had been invented, the former invention enabling several machines to be carried on board special seaplane-carrying ships. The possibility of carrying and dropping a standard 14-in. naval torpedo was demonstrated at the Naval Review at Spithead in July, 1914, and the torpedo was to be

[1] *Short History of Royal Air Force*, p. 259.

one of the principal weapons of offence used by the seaplanes. It soon became apparent that the seaplanes available were not possessed of sufficient carrying capacity, and this indicated the direction in which improvement in design was to be sought. The 184 Short seaplane of two-float type with the new 225-h.p. Sunbeam engine was flown early in 1915. It was primarily designed for torpedo carrying and has survived as the standard type of float seaplane. It took part in operations at the Dardanelles, and it was in this theatre of war that, for the first time, ships were sunk by means of torpedoes released from aircraft in flight. The Wight seaplane was of similar type, but its aerodynamical qualities were inferior to the Short type, and it did not long remain in service. In the early months of 1915, the Sopwith Aviation Company produced a small single-seater float seaplane from the original seaplane designed and built by them for the Schneider Cup Race of the preceding year. This type had a considerable measure of success at the time.

The above-mentioned seaplanes were used principally for coast patrol work. The Fairey Campania seaplane was designed in 1916 for reconnaissance purposes with the fleet, and was specially adapted to suit the conditions on the seaplane carrier H.M.S. "Campania." It was found that seaplanes were not very well adapted for use with the fleet. The carriers had to reduce speed, and stop when the seaplanes were hoisted in and out, a dangerous manœuvre on account of submarines, and as a result of these difficulties small single-seater and two-seater aeroplanes were used instead.

In the summer of 1915, the Royal Naval Air Service was undertaking many duties which were not strictly of a naval character, and the attention of the authorities became concentrated on the production of land aircraft, rather to the exclusion of seaplane development. Experiments were made at the end of 1916 with torpedo aircraft flown from the decks of ships, and aeroplanes were developed for this purpose, so that seaplanes were discarded for this purpose also. The Sopwith Cuckoo appeared in June, 1917. It was fitted with a "land" undercarriage and, though designed towards the end of 1916, is considered the best machine for torpedo work ever produced. Towards the end of 1917, a torpedo aeroplane was required to carry the Mark VIII torpedo weighing 1,400 lb., and the Short "Shirl" and Blackburn "Blackburd" were designed for this purpose. It was not, however, until 19 October, 1918, that the first torpedo squadron was completed for the Grand Fleet.

When, in 1917, the submarine menace raised a demand for bombing seaplanes, it was found that boat seaplanes were a more suitable type for the purpose than float seaplanes, and the result was that the latter type of aircraft was improved during the war less than any other. The development of the boat seaplane at Felixstowe began in the first days of the war, when Commander Porte came back from America with the first twin-engined Curtiss boat. This machine, known as the "Small America," was much inferior to the standard two-float type from the Service point of view, but it laid the foundations of nearly all later developments in boat seaplanes. From it was developed

the "Large America" (Curtiss H.12), which did much useful service against submarines. This machine was designed for the 160 h.p. Curtiss engine, but was afterwards fitted with Rolls-Royce Eagle VIII engines. Another development of the "Small America" was the Porte Flying Boat. It was similar in general design to the "Small America," but was much larger. It had three Rolls-Royce Eagle engines—two driving tractor airscrews, and one a pusher airscrew. The first was in commission in August, 1916, and by the end of 1917 a contract for 10 machines which had been placed with the Aircraft Manufacturing Company had been completed. These Porte boats were too slow and vulnerable to be much employed, but they demonstrated the advantages of the large boat seaplane in its greater seaworthy qualities, its unequalled facilities for observation purposes and its comfort for the crew in flights of long duration.

Experience with the "Small America" and the first of the "Large America" type had shown that the form of hull was not satisfactory. It had been found that the position of the single step and the more or less flat floor, which tended to pound in disturbed water, rendered rising from a seaway a dangerous operation. Experiments with the "Small America," begun in 1915, culminated in the production of the F.1 hull, to which were applied the "Small America" wings and engines. This was the first of the F-type boats, the hull being provided with two shallow steps applied outside the skin of the main hull, a pronounced V-section of floor being maintained from step to stem-post. This machine demonstrated the advantage of the V-bottom in absorbing the shock of landing and taking off a seaway. A new hull was constructed on the same principle for the "Large America," and was substituted for the old type in the summer of 1916. This formed the basis of the F.2 seaplanes which were designed and built in 1917 and 1918. The F.3 was built on the same lines, but on a larger scale, early in 1917. It was designed to be able to go as far as Heligoland and back under its own power. It was capable of carrying 7½ hours' fuel at full power, two 230-lb. bombs or four 112-lb. bombs, a crew of four, wireless installation, etc., and it had a maximum speed of about 80 knots.

Seaplane design policy became very clearly defined in 1918 and centred on the development of larger boat seaplanes. The first type, the N.3, was an enlargement of the F.3 type, with a greater degree of seaworthiness and a longer endurance. The N.4, a still larger type, was in process of development at the time of the Armistice.

(*d*) IMPROVEMENT IN ARMAMENT AND EQUIPMENT.[1]

The equipment and armament of aircraft has been almost entirely a war development. Armament was practically non-existent in August, 1914, and navigation instruments had not been developed in a satisfactory manner. Navigation mainly depended on map reading. Machines were fitted with compasses, but these were of indifferent

[1] Based on *Some Developments in Aircraft Design and Application during the War;* Air Ministry Technical Handbooks; HIST. REC./H/1960/2.

design and could not be relied on unless frequently checked by a view of the ground. The design of an aeroplane compass presents special problems, and the errors involved in using nautical compasses had not been realised before the war. There are great advantages in being able to fly for long distances through clouds, when bombing, and special research was undertaken to make this practicable.

By the middle of 1916, R.A.F. Mark II, a compass adapted for use in an aeroplane, had been evolved from a purely nautical instrument. The faults of the original flat compasses for aeronautical work were partly due to the engine vibration, which would sometimes give a steady deflection of some 40°, but the most difficult problem to solve was the failure of this type of compass to register turns off north under certain conditions. When turning with a heavy bank, the card in any compass remains parallel to the plane of the machine, the consequence being that the effect of the horizontal component of the earth's force diminishes with the angle of bank, and that of the vertical component increases. The north end at once has a tendency to dip and the instrument is no longer a compass in the ordinary sense. This difficulty was mitigated in the "upright" type and in the Lucas Mark II R.A.F. (named after the late Dr. Keith Lucas, F.R.S.), by giving the card a very slow period of swing. The working of both these types gives an appearance of extreme sluggishness. A quicker period had to be introduced into the upright type, and the danger of the northerly "turning error" had to be accepted as an unavoidable nuisance. These compasses, in conjunction with an instrument called a turn indicator developed during 1918, enable a pilot to steer a straight course through clouds. Directional wireless was not evolved in time to be of use in this connection during the war.

The types of altimeter in use early in the war registered heights up to 6,000 or 10,000 ft., and the latter at the outbreak of hostilities was considered an ample maximum height, the average flying height being 3,000 to 6,000 ft. The range and accuracy of anti-aircraft guns increased so rapidly that by the end of 1915 20,000 ft. was within reach of the guns and the range of altimeters had to be increased.

During 1917, the increased altitudes at which machines were capable of flying necessitated the production of suitable oxygen-breathing equipment. Towards the end of the year a great deal of experimental work was carried out, and apparatus was produced capable of supplying oxygen in quantities as required by pilot or observer. The apparatus comprised steel cylinders containing oxygen gas at 150 atmospheres pressure, a regulator controlling the delivery of gas and a mouthpiece or mask for the aviator. Experiments were also made with a view to producing suitable liquid oxygen apparatus, but they did not mature before the Armistice.

The aircraft in use during the early months of the war had been designed without much consideration for armament, and in many it was difficult to fit a gun at all. Until the end of 1915, those aeroplanes and seaplanes which carried guns carried them on very crude mountings improvised by the squadrons in the field, most of them being of the

top plane type, where the gun was fitted in an almost inaccessible position and arranged to fire over the top of the propeller. It was not until aircraft was evolved where the passenger seat was placed behind that of the pilot that a satisfactory observer's gun could be fitted. In pusher aeroplanes the observer occupied the front of the nacelle and could get a fairly satisfactory arc of fire, but no adequate protection could be provided against attack from behind.

No standard gun mountings were available until the autumn of 1915. The first one used in the Royal Naval Air Service was the Scarff Socket and Pillar Mounting, which consisted of a number of posts on either side of the structure and a socket attached to the gun to enable its position to be readily changed from side to side of the machine as required. This mounting, though still extensively used in airships and some aeroplanes, was only designed to cope with the shortage of guns at that period and to fill the gap until the "Scarff Ring Mounting" could be produced. The first of this type, known as the "Scarff No. 1," was an extraordinarily ingenious device and was fitted with a compensating sight which allowed for the correct amount of deflection for own and enemy speeds being applied automatically. At the period of its introduction it was looked on as a great invention and was a considerable advance upon anything previously fitted, but owing to lack of facilities for training in its use, and to the fact that it was not generally understood, it fell into disuse in favour of the "Scarff No. 2 Ring Mounting." This was first fitted to the Sopwith 1½ Strutter early in 1916, and provided for freedom of movement of the observer's gun, hitherto unobtainable on any other mounting. From that date this mounting was in universal use by the British air services and Allies.

The mounting consists of a fixed ring fitted round the top of the observer's cockpit; rolling on this ring is a movable ring on which an elevating bridge is carried—the weight of the gun or guns being suitably balanced against gravity by means of elastic cord. The observer sits within the ring, which is capable of rotation in any direction. The elevating arm enables the gun to be brought above the observer's head for firing upwards or depressed to the level of the fuselage for firing down; thus the gun is easily manœuvred into any position for offensive or defensive purposes by a simple manipulation of a single lever, the mounting being locked at will. In later practice, two guns were fitted to these mountings, arranged to fire simultaneously and parallel to each other. To facilitate the fitting of two guns in a better manner than was possible on the Scarff No. 2 mounting, the Scarff No. 6 was invented. To overcome the difficulty of moving the mounting against the slipstream of the propeller, which has become more apparent as the speed of machines has increased, a wind balancing gear is provided which relieves the observer of much fatigue at high altitudes. This mounting, though in production at the Armistice, did not come into use on active service.

The advent of aerial fighting towards the end of 1915 emphasised the need for a gun capable of firing straight ahead in a tractor aeroplane between the blades of the airscrew. The danger of hitting the airscrew

made it necessary with an ordinary machine gun to aim the gun at an angle, and this restricted the field of fire. Attempts were made to overcome this difficulty by fitting deflector plates made of steel to the blade of the propeller. A fairly successful application of this was made on the Morane type, but in view of the loss of about 10 per cent. of the rounds which were hit by the plates and the reduction of the speed of the machine by about 15 miles per hour,[1] this system was abandoned. The next step to overcome the difficulty was to fit the Lewis gun to fire over or at the side of the airscrew. Later, it was found that more accurate shooting was obtained by aiming the aeroplane rather than the gun, and the gun was mounted on stands on the top plane in a line practically parallel to the airscrew shaft.

Meanwhile, experiments were being made with a synchronising mechanism to enable the Vickers gun to fire through the propeller. The Lewis gun did not lend itself to working with an interrupter gear. The purpose of the mechanism was to ensure that no propeller blade was in the line of fire at the moment when the bullet passes through the plane in which the propeller revolves. The first such gear to be evolved was the Scarff Dibowski, which consisted of a cam driven by the engine, and operated the trigger of the gun through a series of push rods. This gear was very successful, but was superseded by the Sopwith Kauper Gear, which was easier to manipulate. The Kauper Gear was a mechanism designed to run at twice engine speed, and was used in large quantities during 1917 and 1918 on Sopwith Camels.

In May, 1916, Mr. George Constantinesco, the inventor of wave transmission, started experimental work with a gear designed to operate through a pipe-line of oil under pressure by means of impulses transmitted through the fluid. In view of the rapidly increasing number of types of machine and engine and the difficulty of designing a mechanical gear which would be standard for several of them, great attention was paid to the development of the "C.C." gear, as it was called. It involved only a pressure pump, an attachment on the gun, another on the engine, and a copper pipe and feeding apparatus connecting them. Preliminary trials were carried out with a B.E.2c machine in August, 1916, and experiments were made with gears running at half engine speed, engine speed and twice engine speed. Eventually, excellent results were obtained with the gear running at twice engine speed, which ensured that the rate of fire was not appreciably diminished with a falling off of engine revolutions. Extensive trials in the air were carried out at Orfordness in September. As machines became more manœuvrable and sensitive on the controls, it was found that a pilot was liable to move his aim off the target when firing the gun, owing to the pressure on the control lever, and an arrangement was made by which the gear could be put in or out of action by means of a simple Bowden lever on the control lever of the machine. By the beginning of 1917, these gears were being fitted to various machines.

[1] Hist. Rec./H/1960/2.

In May, 1917, there was developed from the "C.C." gear, type "B," an arrangement comprising one reservoir, one generator and a main pipe-line, leading to a Tee-joint and so to two trigger motors. This was used for the twin-gun installation on the Le Rhone Camels. About the same time the type "C" gear was developed. This consisted of a reservoir with twin control needles, smaller self-contained trigger motors and generator with rollers on their plungers, operated by large size cams carried on the engine. The advantage of this design was that, except during the actual firing of the gun, the whole of the gear was at rest. Both these types of gear were used on machines in large quantities and gave excellent results. Hit propellers became a rare occurrence, about one per 25,000 rounds. In conjunction with the Hazelton speeding-up device on the gun, a rate of fire of 800 rounds per minute was frequently obtained. Some idea of the extent to which the Constantinesco gears were used can be obtained from the fact that some 6,000 were issued during the period March to December, 1917, and some 20,000 during the period January to October, 1918. In October, 1917, arrangements were made to replace the Sopwith Kauper gears by the "C" type "C.C." gear in order to standardise one type on all machines.

Experiments were made with synchronising gears for the Lewis gun owing to shortage of Vickers guns, but the latter were so satisfactory that work was subsequently stopped on the Lewis gun.

The Vickers gun became the standard pilot's gun in the Air Force, being fixed to the machine and fired through the airscrew by synchronising gear controlled by the pilot. At first the ordinary ground pattern web belt was used for loading the cartridge. The full belt was contained in an ammunition box and arrangements were made to wind off the empty belt as it left the gun on to a drum rotated by "shock absorber." This system proved very unsatisfactory. Imitating the method used by the Germans, a form of disintegrating belt was designed, and the links left the gun separately and were wasted down a chute. The ground pattern gun was in many ways unsuitable for use in the air. The most necessary alteration was the substitution of air-cooling for water-cooling. By perforating the barrel casing, use was made of the cold air and weight was saved. The use of two Vickers guns side by side in a machine made it very desirable that the gun should be capable of being fed in some cases from the left-hand side, and a left-hand feed block instantly interchangeable with the right-hand feed block was therefore designed and made. Another improvement made to the Vickers gun was the fitting of the Hazelton speeding-up conversion set. This device increased the rate of fire of the gun to about 1,000 rounds per minute.

The Lewis gun was the machine gun first adopted for use on aircraft on account of its lightness. Later, when interrupter gears came into vogue, this gun was found unsuitable for firing by mechanical means and was subsequently used as the standard weapon for observers and gunners. It was not, however, until the middle of 1916 that they were available for the air services in large numbers. The gun as fitted for land work, with large barrel casing and radiator fins

for cooling the barrel, was unsuitable for aircraft work on account of its weight and big head resistance. A course of experiments showed that the gun worked satisfactorily with a bare barrel, the passage through the air providing the necessary cooling, and all that was necessary was a small light casing over the gas cylinder to preserve it from accidental damage. Electric heating had to be adopted both with the Vickers and Lewis guns to prevent freezing of the oil at great altitudes.

It was essential to fit special sights for all machine guns used on aircraft, as those originally supplied with the guns were unsuitable for use in the air, owing to the fact that no means were provided of estimating the allowance to be made to compensate for the velocities of "own" and "enemy" machines. Both the Royal Naval Air Service and the Royal Flying Corps adopted the "ring" or "graticule" system of estimating allowances for enemy speed and evolved sights similar in principle but differing in method of use. With a fixed gun firing through the airscrew no allowance was necessary for "own" speed, as the axis of the sight was in the direction of motion of the machine, but with movable guns correction was necessary for both "own" and "enemy" speeds. The ring sight takes the form of a thin circular band of metal having a smaller concentric circle within it. The radius of the ring is arranged proportionately to its distance from the observer's eye to give the correct deflection for the enemy's average speed. With a fixed gun this ring sight is used in conjunction with a bead sight consisting of a bead mounted at the top of a pillar. By aligning the bead with the centre of the ring the line of fire is given, and to ensure that the enemy's line of flight intersects the line of fire the gunner must manœuvre until the hostile machine is apparently running directly towards the centre of the ring and the bead placed central thereto. Aim is then taken by placing the target within the ring.

The Royal Flying Corps sight vane, more properly known as the Norman vane fore-sight, was the standard one in use with a movable gun at the signing of the Armistice. It comprises a bead and a vane mounted one on each side of a central rotating pillar, and connected by arms which allow of reciprocating movement. The base of the central pillar is fixed on a mounting fitted to the fore-end of the barrel of the gun. The sight is used in conjunction with a ring, and the distance between the bead pillar and the central pillar is arranged, with relation to the distance between the central pillar and the ring, in such a way as to make these distances proportional to the two forces acting on a bullet fired from a movable gun, *i.e.*, the force due to the momentum, and the force due to the explosion. Thus allowance is made for "own" speed. The vane is acted on by the slipstream, so that the axis of the sight is always parallel to the line of flight of the machine, no matter how the gun is pointed. In using the sight the bead is aligned on the centre of the ring, and the target is then "placed" in the ring.

In some instances the ring has been mounted in a telescope of unit magnification, one of the best examples of which is the Aldis sight. Within the tube is a screen carrying a large circle and a smaller

concentric ring together with 12 radial lines. The principle is the same as for the ring sight, but by virtue of the arrangement of lenses it is not necessary for the gunner to align a back-sight and fore-sight or to maintain an exact sight base, for as long as both circles are visible the position of the eye does not matter, the ring always being seen with its centre on the object at which the tube is pointing. With this sight, it is only necessary to place the enemy machine in the proper position on the ring to ensure the correct aim. Special ring, bead and Norman sights have been successfully illuminated for night flying. At the time when the Armistice was signed, promising results were being obtained on the Jenkin day and night sight, a somewhat similar device to the Aldis unit magnification sight.

At the beginning of the war, the only available ammunition for use in aircraft guns and rifles was S.A. ball. At the end of 1914, Mr. Buckingham evolved the idea of a phosphorus-filled bullet, and, before the end of 1915, an incendiary bullet, the ·303 in., with a tracer range of 700 to 1,100 yards, was produced. About the same time, Woolwich was experimenting with a tracer and the S.P.G. was produced and issued to the service early in 1916. Each of these bullets had its special functions, the Buckingham having the superior incendiary effect for use against balloons, petrol tanks, etc., while the S.P.G. had the better day tracer effect. Two other types of incendiary bullets, the Brock and the Pomeroy, had been developed by the middle of 1916. Another incendiary bullet, the R.T.S., was produced late in 1917. The use of tracers for aerial fighting first took place at the end of 1915, when Lieut. Sims brought down an enemy aeroplane in flames with Buckingham ammunition. From then onwards this bullet, and later the S.P.G., had a most potent effect.[1] Owing to the introduction of synchronising gears for firing with the Vickers gun through the airscrew, the reliability of the caps and charges of machine gun ammunition became of great importance. A very exacting system of testing, weighing and centreing of caps in aircraft ammunition was enforced, resulting in the practical elimination of all missfires and shot airscrews.

The question of "heavy gun" armament for aircraft was under consideration in the early days of the war. In fact, in the spring of 1914, a 1-pdr. Vickers automatic gun was mounted in a Short pusher biplane, and the gun was fired from the machine during flight. Nothing further was done at that time, but the advantage of a large-sized gun and projectile was apparent, especially for attack on arsenals, docks, or magazines, and in January, 1915, the first order for 1-pdr. guns for use in aeroplanes was placed for the Royal Flying Corps with Messrs. Vickers. It was not until the beginning of 1916 that one of these guns was mounted in an F.E. aeroplane, since a good deal of experimental work had been necessary in connection with the mounting and ammunition. At this time, Zeppelins were considered one of the most important objectives for these guns, and special incendiary ammunition was necessary. At the same time the Royal

[1] For further details concerning the development of special aircraft ammunition, see Vol. XI, Part VI, Chap. VI.

Naval Air Service was carrying on experiments with heavy guns mounted in various machines. The 6-pdr. Davis gun, mounted in a Handley Page machine, was the only combination which saw actual service.

During 1916 designs were prepared by Messrs. Coventry Ordnance Works of a special high-velocity 1½-pdr. fully automatic gun of 37 mm. calibre, and by Messrs. Vickers of a low velocity Q.F. gun of 1·59 in. calibre. The Coventry gun was then, and still is, the lightest gun available. It gave the required velocity, 2,000 ft. per second, to a 1½-pdr. shell, thus fulfilling the conditions required for aerial fighting. The utility of the Vickers Q.F. guns was limited to attack on ground targets, and they have been successfully used in F.E.2.b aeroplanes. In the early part of 1917, trials were carried out with 47 mm. Hotchkiss guns and with 6- and 12-pdr. Davis guns to determine their usefulness in anti-submarine warfare. Special ammunition was designed and a good deal of experiment was necessary with the fuses, for existing percussion fuses were not sufficiently sensitive and the ordinary type of time-fuse was entirely unsuitable under the varying barometric conditions consequent on rapid change of altitude.

The different types of aerial bombs evolved during the war have been dealt with in another section.[1] At the end of 1914, the only standardised carriers in service were the single 16-lb. bomb dropping gear and the 20-lb. bomb dropping gear for two Hale 20-lb. bombs. In each case the carrier consisted of a longitudinal channel with a fixed nose-crutch at the front and a spring crutch at the rear for steadying the tail end of the bomb. The releasing mechanism consisted of a hook lying on its side at the bottom of the channel and engaging the eye on the side of the bomb projecting through a slot in the bottom of the channel. The hook when carrying the bomb was held in place by a flat spring inside the channel, and a coiled tension attached to the tail of the hook projecting through the side of the channel. To this tail was also attached the Bowden wire for releasing. With the introduction of higher-powered machines, particularly seaplanes, in 1915, the useful load was greatly increased and a considerable amount of work was done in evolving carriers for larger bombs than those of 10 to 20 lb. hitherto in use. Carriers for four or eight 16-lb. or 20-lb. bombs abreast were produced. At the beginning of 1915, the first practical 112-lb. bomb carrier was evolved, and towards the end of the year the Royal Flying Corps developed their standard single and twin 112-lb. carriers. In this year also the Woolwich 520-lb. and 550-lb. carrier was produced, of the same general type as the 112-lb. carrier. An interesting advance in bomb armament was made when Messrs. Short designed and fitted a 520-lb. carrier under the fuselage of one of their 225-h.p. seaplanes. This carrier, which was very much lighter than the Woolwich 520 lb. type, was provided with a sleeve-type slip, and the weight was not taken on the carrier body itself, but distributed by cable to four points on the fuselage.

[1] Vol. XII, Part II.

The two most important developments in aircraft bomb gear in 1916 were, the introduction of the Skeleton type of bomb release-slips and carriers and the principle of vertical stowage of bombs inside the fuselage. The Skeleton-type carriers were made in three sizes, 112 lb., 250 lb. and 520 lb., and were very light and of low head resistance as compared with other carriers. The 520-lb. type, for instance, weighed 16 lb., whereas the Woolwich 520-lb. carrier weighed 90 lb. In the method of vertical stowage, the bombs are hung by the nose on release-slips mounted on beams, the bombs being steadied when in place and guided during their fall in cellular compartments. The early types of bombing aeroplanes carried their load of bombs beneath the fuselage or under the wing, but in all the later designs external stowage was discarded altogether, on account of its interference with the performance of the machine.

Bomb sights were practically unknown in 1914. At the beginning of 1915, a simple lever with an angle scale was used as a bomb sight. The table of angles was carried in the machine, but during 1915 the C.F.S. bomb-sight scale was invented. This was the first notable advance towards bomb-sighting accuracy, and was adopted both by the Royal Naval Air Service and the Royal Flying Corps. The equal-distance bomb sight was introduced in the Royal Naval Air Service during 1916, taking the place of the C.F.S. for operations over the sea. Low-height drift sights for seaplanes and high-altitude drift sights were designed during 1917. The latter was adopted for all the Naval Air Service De Havilland machines, and in 1918 it became the standard for all land-bombing machines operating at over 1,000 ft. The introduction of formation bombing for purposes of self-defence tended to reduce individual responsibility for obtaining line and wind, and led to the provision of meteorological information enabling adjustment for wind to be made before ascent.

On the outbreak of war no considerable signalling system existed for the use of aircraft, and night-flying was not indulged in on a large scale. The growth in importance of aircraft in warfare led to the introduction, first, of landing lights to enable the machines to land by night, and subsequently to the development of parachute flares for the purpose of night reconnaissance. By the end of 1915, the only pyrotechnical stores in general use were the Holt landing lights (fixed to the wing tips), the Holt pilot light (a small parachute flare now obsolete), a smoke bomb for daylight signalling, and Véry cartridges with single plain coloured stars. The reconnaissance flare produced by the Michelin Company was first employed in 1916, and this flare, recently much improved by increase of light, was the standard flare until the end of the war. During 1918, the demand for pyrotechnical stores increased enormously and reconnaissance flares were sub-divided into two types of four minutes' and seven minutes' duration respectively. Another similar type of flare, giving an instantaneous flash of enormous candle-power, was evolved for purposes of night-photography. For anti-submarine work a very large flare was designed for suspension below an observation balloon.

At the beginning of the war electricity was not used on aircraft to any appreciable extent, but its use has been developed in various directions, and by November, 1918, practically all aircraft carried a complete electrical installation, comprising one or more wind-driven generators, which supplied energy for such diverse purposes as wireless telegraphy and telephony, electric lamps of all descriptions, electrical heaters for guns, oxygen apparatus and clothing, and various types of signal devices. All this electrical gear had to be specially designed for Service requirements, the ordinary commercial apparatus previously in existence not being sufficiently light or efficient for use in the air.

CHAPTER II.

METHODS OF SUPPLY, 1914–1916.

I. Admiralty Arrangements for Design, Supply and Inspection.

(*a*) Headquarters Organisation.

The Air Department was formed at the Admiralty in September, 1912. The Director, Commodore M. F. Sueter, was responsible to the various Sea Lords for different sides of his work, as has been already described.[1] He was placed in direct communication in matters of detail with the Air Staff at the War Office, but decisions of general and important aeronautical questions were notified officially by the Secretary of the Admiralty to the War Office and *vice versa*. The Royal Aircraft Factory nominally existed as a Technical Department for both Services, but the Admiralty made small use of its resources and developed an independent Technical Department.

The Royal Naval Air Service (so called since June, 1914) was completely reorganised in September, 1915. The Director of the Air Department was superseded by the Director of Air Services (Admiral Vaughan-Lee), in whom was vested considerably extended power and responsibility. The Air Department was reorganised, with Organisation and Construction Branches. A Naval Assistant attached to the Organisation Branch made proposals as to the numbers and types of aircraft to be embodied in the programmes submitted to the Board of Admiralty, allocated aircraft to the various stations and dealt with questions relating to the transfer of completed machines to the War Department and to foreign Governments.

The Construction Branch was divided into three sections, dealing respectively with armament, airships and kite balloons, and aeroplanes and seaplanes. The Armament Captain (A.C.) was responsible for all questions relating to the armament of aircraft, and also for training in armament and gunnery. He dealt direct with the Superintendent of Ordnance Stores in questions relating to guns, small arms, bombs and ammunition, but questions involving the supply and cost of purely aviation stores, such as bomb sights and gear and gun mountings, which did not come under the Ordnance Vote, were referred to the Supply and Finance Sections. The Assistant-Superintendent for Airships dealt with all questions relating to construction of rigid airships other than those dealt with by the Director of Naval Construction and the Engineer-in-Chief, and with all questions relating to the construction of other airships, kite balloons and fabric, and to the supply of hydrogen and hydrogen plant.

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[1] See above, p. 3.

The Aeroplane and Seaplane Construction Branch was divided into three sections under Assistant-Superintendents of Design, Production and Engines respectively. Under the Assistant-Superintendent of Design were the Designs Office, the experimental pilots and an Acceptance Organiser. He was responsible for all new types of aeroplanes and seaplanes until the machines had passed their design trials and were handed over to the Production Section. While experimental machines were under construction, he was informed of their progress by his inspectors at the works, and was responsible for seeing that no avoidable delay occurred in production. He also kept in touch with research made by other authorities, received reports from the Services and investigated new designs from all sources. In conjunction with the Production Section he arranged a suitable distribution of design work through the various firms. He arranged the programme of work for the Repair Depôt at Port Victoria, superintended the work of experimental flights, design trials, and experimental work in connection with seaplane carriers. He was also responsible for specifications, and, as the representative of the Construction Branch on the Advisory Committee for Aeronautics, issued the report of the Committee to all concerned and prepared and issued technical memoranda on construction. The Assistant-Superintendent of Production was in charge of Admiralty inspectors at private works (except those superintending the construction of experimental machines). These inspectors informed him of the progress of work at the factories, and he allocated orders accordingly. He was also responsible for questions of priority, dilution of labour, and badges, for the supply of raw material and for the settlement of all questions causing delay in output. He advised as to fair prices and issued weekly statements of progress of work and anticipated deliveries. The erection of American machines was also under his supervision. The Assistant-Superintendent of Engines dealt with all questions relating to design, supply and repair of engines. He dealt with specifications for material and inspection of material ordered to these specifications, and with all questions of labour priority and dilution in engine firms.

In accordance with the general principles of the Admiralty's organisation, the contracts and finance duties relating to aircraft were undertaken by departments which were already responsible for similar duties in respect of ships of war. The most serious financial problem which arose at this time was the question of prices. These presented peculiar difficulties, owing to the universal lack of experience in manufacture, and the rapidity in the development of design. Often it was impossible to come to any final decision in this respect until the order was practically completed. The alternative, however, would have resulted in pure speculation. In some cases firms were given a contract advance and in such a case progress payments were not made until the value of the contract advance had been cleared.[1]

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[1] DF 3/P.A.C./20; A.S. 2977/1918.

(b) DESIGN, PRODUCTION AND INSPECTION.

At an early period in the war the Admiralty adopted the policy of granting a number of Royal Naval Volunteer Reserve temporary commissions to engineers for technical duties with the Royal Naval Air Service, thus securing at the outset engineering talent which proved invaluable as the war proceeded. These officers undertook innumerable duties connected with inventions and design, inspection and production.

The Design Branch of the Admiralty Air Department consisted on the outbreak of war of a staff of three. It was augmented on 18 August by two more officers, and no further increase took place until March, 1915. The Branch was then divided into three, a drawing office, a Stress Section, and a Propeller Section, responsible through the head of the branch to the Director of the Air Department. The policy adopted was to encourage private design work, and the Royal Naval Air Service was so placed that the policy could be pursued with the best results. The knowledge of manufacturing resources, and the prestige of the naval service among engineering firms, constituted a natural advantage in providing magnetos, engines and components which would otherwise have been difficult to obtain, and, in consequence, firms who were working on Admiralty contracts were exceptionally well situated from the point of view of obtaining material. In addition, most of the firms employed on Admiralty contracts for aeroplanes were pioneer aircraft firms. The design of a limited number of types was carried out in the drawing office of the Design Branch, but this system did not produce very satisfactory results, owing to the absence of any facilities for constructing machines and evolving a satisfactory commercial product. The Stress Section criticised design and suggested improvements, and the Propeller Section prepared airscrews to suit any machine and investigated theories controlling their design.

The production officers, stationed at contractors' works and qualified to act as local representatives of the Director of Air Services, possessed extensive discretionary powers and had sufficient authority to cope with most of the difficulties arising out of production. No detailed inspection was carried out, one officer as a rule being allocated to a group of two or three firms, with three or four subordinates resident at each of the firms, to provide a general supervision of the firms' own inspection. Flight tests were usually carried out by the firm's pilots before acceptance by the Service. Towards the end of 1915 the Port Victoria air station, adjacent to Grain air station, was formed for carrying out experiments on new types of machines, both aeroplanes and seaplanes. A test flight was formed at Eastchurch and the Royal Naval Air Service aeroplanes were sent there instead of to Grain. This arrangement continued until late in 1917, when it was decided that all land machines should be tested at Martlesham Heath.

During the early months of the war reliance was temporarily placed on imported supplies of engines, while the British industry, practically non-existent before the war, was in process of building up. The production of British engines introduced a new problem of supply,

and the Engine Branch developed independently of, though in liaison with, the branches for design and production of aircraft. In 1916 it was realised that the technical staff of the Royal Naval Air Service would have to be augmented to secure a greater output of engines. Officers were posted to various works manufacturing engines for the Navy only, and constituted the production side, while others formed the headquarters technical and administration staff, with headquarters at Victory House, Trafalgar Square. The headquarters staff soon became divided into subsections, one dealing with technical questions relating to engines, radiators and installation, a second with the distribution of engines to aircraft makers, a third with the ignition problem, a fourth with materials, a fifth with carburetters, and a sixth with ground plant and equipment of air stations. Later a division was made between production and inspection on the one hand and technical work on the other.[1] The officers stationed at the works carried out various duties connected with supply and production, such as assisting firms in obtaining material, helping those backward in delivery, securing contractors for the manufacture of jigs and tools, watching progress and manufacturing processes, drawing attention to any defects in works organisation, and inspecting machining operations, assembling, erection and testing. The work was facilitated by frequent conferences and reports.

(c) Foreign Supplies.

On the outbreak of war it was immediately realised that a large number of French machines and engines would be required to cover the period during which the foundations of British industry were being laid. In the latter part of 1914 a representative of the Admiralty was detailed to procure aviation material in France, and he placed certain orders direct with French contractors. Subsequently the French Government took over the entire output of French aviation material, and the French contractors were therefore unable to fulfil their contracts with the British Government. It was, therefore, arranged in December, 1914, that these contracts should be regarded as cancelled, and that the French Government should be asked to supply the material required. Thereafter orders were placed subject to the consent of the French Government. The original request to the French was for a period of three months, but this was extended from time to time.[2]

A military representative had been dispatched to Paris on the outbreak of war to superintend the purchase of material for the Royal Flying Corps, and, in order to avoid competition between the representatives of the Army and the Navy, a joint commission was formed in January, 1916, for the purchase of aeronautical material in France for both Services.

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[1] A.S. 43215/1918. [2] D.F. 3/P.A.C./20.

The system of purchase adopted was found unsatisfactory since the French aviation firms were unable to meet the demands made upon them by all the Allies, and there was no means of securing deliveries under the British contracts. Towards the end of 1915 the French Government undertook the allocation of the output of the French firms between the Allies and became responsible for securing the deliveries allocated to the British Government.[1] About the middle of 1916 it became apparent that French aero-engine capacity was becoming exhausted, and with a view to drawing new firms into the industry a new system of purchase was adopted. Contracts were placed direct with French firms who had not hitherto been engaged in the manufacture of aero-engines, with the approval of the French Government, who abstained from placing with these firms orders for other war material. These contractors were allowed to charge the British Commission 20 per cent. above their prices to the French Government. The materials were supplied from England, but the French Government furnished the necessary labour. This arrangement was revoked in December, and most of the subsequent contracts were placed by the British Commission jointly for the Allied Governments at an agreed price, the output being divided in an agreed proportion. Orders for spares were placed through the French Government.[2]

The 200-h.p. Hispano-Suiza, an engine of Spanish design, built in France, came into prominence early in 1916. Large contracts were placed in Paris with a number of firms. The firm of Mayen constructed a large factory for building the Hispano-Suiza and the 130-h.p. Clerget. Considerable advances were made by the British Government to finance this undertaking, but it did not mature during the period while the Admiralty and War Department were in charge of supply.[3] The Admiralty purchases in France, both of engines and aeroplanes, continued to be very large throughout the period during which they were responsible for supply. Indeed, the French market constituted their main source of supply of land machines, while the development of manufacture among new British firms was small. Thus, of about 30 British firms employed on Admiralty aeroplanes and seaplanes, all except seven had been pioneers in aeronautical work before the war.[4] The total number of engines of French manufacture supplied to the Services during 1915 was 883, and during 1916, 3,104, consisting chiefly of the rotary types, Clerget, Le Rhone and Gnome. The aeroplanes supplied during 1915 and 1916 were 451 and 666 respectively,[5] and included Maurice and Henri Farmans, Moranes, Bleriots and Nieuports, besides various other types.

The Admiralty in pursuance of a policy of buying in any available market, also placed large orders in the United States. In March, 1915, the Treasury approved certain purchases to the amount of £900,000, of which it was proposed that £629,000 should go to Messrs.

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[1] C.R.F.C. 1868/6 Q. [2] A.S. 1276/1917. [3] See below, Chap. III.
[4] *H.M. Naval Aircraft, built, building, and under repair, January,* 1917.
[5] *Review of Munitions Output,* 1914–18. (Copy HIST. REC./R/1000·1/3.)

Curtiss' firm, and an order was placed for 100 R.2 aeroplanes. An officer was despatched to America in connection with these orders, and by the middle of April, 1915, the Admiralty was committed to taking the whole of the output of the firm for the year, the total commitment to the Company amounting to 11,000,000 dollars.

Definite orders for the various machines to be delivered were not given pending trials, but in April, 1916, a definite order for 100 "Canada" machines with 160 h.p. engines was placed. Owing to unsatisfactory reports of trials all orders were cancelled in June, 1916, except one for 50 "America" boat seaplanes which were to be supplied without engines. The position was so unsatisfactory that in August the Admiralty sent out a representative with full powers to clear up the situation. As a result of the negotiations which followed, the Admiralty secured an adjustment of conditions in respect of undelivered portions of the orders, but was committed to certain payments for work done and loss of profit, as well as to payments for actual deliveries. In September, 1916, a new contract was arranged with Messrs. Curtiss,[1] but the engines and aeroplanes obtained from this source were never wholly satisfactory, though much improvement was effected by sending a Royal Naval Air Service inspector to America to supervise construction. The aeroplanes were chiefly used for training purposes.

II. Supply, Design and Inspection under the War Department.

(*a*) Administrative Organisation.

The original Royal Flying Corps was administered like any other branch of the army, *personnel* being under the Adjutant-General and the purchase of aeroplanes being carried out by the Master-General of Ordnance. A committee for the Royal Flying Corps had been instituted in May, 1912, with Sir David Henderson as chairman, and in practice questions of supply were arranged in the committee, as the Master-General of Ordnance had no special knowledge of aeronautics. For a similar reason the Secretary of this committee worked in practice as a unit of the Military Training Directorate administering the Royal Flying Corps and taking orders from the Director of Military Training. This position was officially recognised in May, 1913, by the abolition of the committee and the formation of section MT4, which was expanded in August, 1913, into the Directorate of Military Aeronautics, with Sir David Henderson as Director-General. The Directorate had its own Contracts Branch and was entirely responsible for aeronautical supplies, and also had full control of the Royal Flying Corps. Aeronautical finance was dealt with by the War Department Finance Branch. The possession by the Directorate of Military Aeronautics of a separate Contracts Branch proved to be a great advantage during the war, owing to the centralisation of information regarding the various independent industries engaged in aeronautical work. When war broke out the Directorate was divided into three sections, MA1, MA2, and MA3. MA1 dealt with

[1] D.F. 3/P.A.C/20.

policy, administration and *personnel*, MA3 was the contracts sub-division of the Directorate, responsible for the purchase and sale of aeronautical material, and MA2 was responsible for the supply and inspection of material and aeronautical equipment generally, for inventions and experiments, and for the administration of the Royal Aircraft Factory and the Aeronautical Inspection Department. The staff of each of these sections was small; the total peace establishment of the Directorate numbered 18, the war establishment 26. MA1 decided policy as to the types and numbers of machines required, and in conjunction with MA2 obtained the approval of the Director-General. When approval was obtained the order was placed by MA3. The duties of MA3 were somewhat wider than those of an ordinary contracts branch. For instance, it dealt with labour for aircraft supply, advised the War Trade Department on export licences relating to aeronautical material, urged deliveries by means of correspondence, and regulated traffic facilities for aeronautical material.

Sir David Henderson combined the offices of Commander of the Royal Flying Corps and Director-General of Military Aeronautics. He was in France during the whole of the first year of the war, leaving Colonel W. S. Brancker in charge at the War Office, but he always maintained the closest touch with supply, and the intimate relationship thus set up between the supplier and the user of aeronautical material was maintained throughout the period during which the War Department was responsible for supply. During 1915 the Royal Flying Corps was called upon to co-operate in other theatres of war besides the Western Front. As the Service grew the continued presence of the Director-General at the Front became impossible, and in August, 1915, he returned to take charge at the War Office. In the previous May expansion and re-organisation had taken place at headquarters. The supply branch was sub-divided. MA2*a* dealt with supply up to the stage when the complete machine or engine was ready for inspection; from that point it was taken over by MA2*b*, which was responsible for equipping and delivering the stores to the Royal Flying Corps.[1]

Towards the end of 1915, the Contracts Branch transferred all its extraneous duties to the supply department, the responsible officer of the department being known by the somewhat misleading title of "Chief Contracts Officer." The supply officers frequently conducted negotiations with contractors, and although the Contracts Branch was throughout the sole authority for placing orders and settling terms the relations between the two departments were of an informal character. This undoubtedly contributed to rapid production, though as the department grew the lack of formality sometimes led to confusion and overlapping.[2]

At the end of 1915 officers who had seen service in the Royal Flying Corps joined the supply branch and laid the foundation for a technical section. The staff of the Designs Branch, which was formed early in 1916,[3] criticised the design of new machines, investigated

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[1] M.A./P/35. [2] 87/Contracts/58. [3] M.A./Headquarters/42.

inventions and, after consultation with the Inspection Department, advised the Director-General as to the adoption of different machines and engines.

In February, 1916, Lord French assumed responsibility for home defence,[1] and the provision of the necessary pilots and aeroplanes was added to the duties of the Directorate of Military Aeronautics. The fighting and equipment branches were divided in April, 1916, and placed under a Director of Air Organisation and a Director of Aircraft Equipment respectively with a Contracts Branch working directly under the Director-General. The Director of Aircraft Equipment controlled the Equipment Branch, Inspection Department and the Royal Aircraft Factory. In May, the Contracts Branch undertook a further extension in other directions of its own work. In particular the scope of the branch dealing with miscellaneous materials and accessories increased with the development of the Royal Flying Corps. Towards the end of 1916 the policy was introduced of making large stock purchases of materials where a shortage was to be expected, and where better production was secured by the placing of bulk orders. The War Department ceased to buy merely for the Royal Aircraft Factory and R.F.C. stores, and bought large stocks to issue to aircraft contractors. As the work of the Contracts Department grew in volume it became necessary to sub-divide the duties, and at the time of the transfer to the Ministry of Munitions the branch was divided into five sections dealing respectively with (1) engines; (2) aeroplanes of private design; (3) aeroplanes of Government design; (4) miscellaneous matters; and (5) general services. The General Services Section was responsible for firms' records, issue and receipt of tenders, and statistics.[2]

Concurrently the Supply Branch also developed. In April, 1916, it was divided into four sections. AE1 and AE2 took over duties roughly corresponding to those of MA2*a* and MA2*b* under the old organisation, and were themselves divided into various sub-sections dealing with particular stores. AE1 took over the production work formerly performed by MA3, the hastening of materials and parts being still carried on from headquarters. In October, 1916, the increased aeroplane programme called for further reorganisation of the Supply Branch, which was then divided into Aeroplane, Engine, Materials, and Hastening Branches, known as AE4S1, AE4S2, AE4S3 and AE4S4 respectively. The Aeroplane Branch was further sub-divided into two sections, one for machines of Government design and one for those of private design. Shortly afterwards the supply of instruments, armament, fabric, tents, etc., was transferred to a new section. The production staff of the Hastening Section was slightly increased and their functions expanded by stationing officers in manufacturing districts to accelerate production, give effect to headquarters instructions and assist manufacturers in obtaining materials and components.

[1] Minutes of Committee on Administration and Command of Royal Flying Corps, 15th Day, 6th July, 1916.
[2] A.S. 43215/1918.

(*b*) TECHNICAL WORK.

On the outbreak of war, technical development of aircraft for the Royal Flying Corps was carried on at the Royal Aircraft Factory at Farnborough, and at the National Physical Laboratory, Teddington. The pre-war functions of the Factory were the production of designs, drawings and specifications for new types of machine and engine, the building of experimental machines, provision of aeronautical stores and execution of repairs, as well as the conduct of full-scale experiments, as distinct from laboratory work. When war broke out, the functions of the Factory were extended to cover emergency work of various kinds to assist contractors or make good their failure. The manufacture of spares and repair of engines became an important branch of the Factory's work. Little was done in actual construction other than of experimental machines and engines of Factory design, but a certain number of aeroplanes were built to keep the capacity usefully employed when not in demand for experimental work. A small experimental department for research on accessories such as photography, wireless, gun mountings, special bullets, etc., gradually developed at the Factory, and attracted eminent scientific men and capable research students. Many of the experiments were of a most secret nature, wholly unsuitable for conducting in a factory of such size, and the branch was suppressed and the work transferred to a small establishment at Battersea Park. It was also found necessary to develop the Factory in certain directions for the supply of materials, either raw or manufactured, which were difficult to obtain from other sources. This led to much experimental work upon alloys, dope and other materials.

The formation of the Technical Branch at headquarters relieved the Factory of its duties in connection with drawings and specifications, and the output of reliable proprietary machines, which formed such a marked feature of the latter months of 1916, made a large output of Factory designs no longer necessary. When the establishment was transferred to the Ministry of Munitions work on original designs accordingly ceased.

Very little flight experimental work was carried out during the first twelve months of the war by the Royal Flying Corps. Numerous experiments were made by contractors, and flight tests were carried out at Farnborough and the Central Flying School, Upavon. The experimental flight was formed at the Central Flying School in the early summer of 1915, to deal with testing of aeroplanes and experiments on armament. The method of testing aircraft at this time was somewhat crude, and consisted of speed tests near the ground over a course about a mile long and a climb of 6,000 ft. with stop watches, or a barograph if such an instrument could be obtained. The standard method finally adopted by both Services in 1917 was not evolved until the removal of the Testing Squadron to Martlesham Heath. If the machine came satisfactorily through its tests, it was sent to France for further trial under service conditions, and was examined for structural defects by the Inspection Department. These trials enabled the authorities to judge whether the machine possessed such advantages over existing types as to make its introduction into supply advisable.

It was found difficult to carry out much work on guns, gunsights, etc., at the Central Flying School, owing to the danger of firing in the air, and in May, 1916, the experimental flight was divided into two sections, one to deal with the testing of aeroplanes at the Central Flying School, and the other to deal with armament work at a new station at Orfordness. In view of the training which was being carried out at the Central Flying School, the number of machines continually in the air hampered the work of the Testing Squadron, which was moved at the end of 1916 to Martlesham Heath.

(c) Inspection and Progress.

The Aeronautical Inspection Department existed as a separate organisation. It originated before the war at the Royal Aircraft Factory. The manufacture of a number of officially-designed aeroplanes for the War Department was at that time carried out there, and, as part of the Factory organisation, an inspection department was instituted and a rigid procedure was developed whereby all raw material entering the Factory was tested in detail in accordance with original R.A.F. specification before being passed into the construction department.

Process examination during manufacture was instituted and a final test and examination of the complete machine was carried out before the aeroplane was handed over to the Royal Flying Corps for service. When contracts for aeroplanes were placed with private firms, it was found desirable to establish a separate organisation solely devoted to the inspection of all aeronautical equipment purchased for the use of the Royal Flying Corps, and the Aeronautical Inspection Department was set up in December, 1913. The department was organised into two main technical branches, dealing respectively with the inspection of aeroplanes and engines.

On the outbreak of war it was at once realised that, for the inspection of the work done by inexperienced firms, a greatly increased staff would be necessary. Great difficulty was found in getting men of the required technical ability, the majority having either joined the Colours or secured positions with contractors. The general control of inspection at contractors' works was placed in the hands of a chief examiner, resident at each of the works, reporting to the Inspector of Aeroplanes or Engines as the case might be. Under these chief examiners at the larger firms, two or three examiners and viewers were placed, each having definite duties allotted to them, such as the supervision of material testing, machine and erection shops and final testing.

The work of the headquarters staff of the Aeronautical Inspection Department comprised much that was not purely inspectional, owing to the fact that the administrative and technical organisation of the Directorate of Military Aeronautics was, perforce, small at that time. The majority of the technical questions raised by the Service on the one hand and by contractors on the other were referred to the Aeronautical Inspection Department; but questions relating to Royal

Aircraft Factory designs were dealt with exclusively at Farnborough. The local knowledge of the inspection staff as to conditions of labour, the capacity of the various firms and the state of existing contracts was placed at the disposal of the Chief Contracts Officer, to assist him in introducing new firms to aircraft work. Before a contract was placed with a new firm a technical report was supplied by the Aeronautical Inspection Department as to the general class of workmanship and working efficiency which might be expected.

The headquarters of the Inspection Department were at Farnborough until the end of 1915, when development was taking place in the Directorate of Military Aeronautics, and the inspectional headquarters staff moved to London and were housed at Albemarle Street with the rest of the directorate. The formation of the Technical Department at the beginning of 1916 relieved the Inspection Department of some of its duties. The new Technical Branch, while assuming full responsibility for the approval of design, modifications and specifications, still left to the Inspection Department power to fix limits and to grant concessions for the use of parts which, though not manufactured correct to drawing, were still serviceable. The reorganisation of the Supply Branch in May, 1915, relieved the Aeronautical Inspection Department of detailed allocation of machines and engines to the Service, and the delivery of engines to aeroplane contractors, which they had formerly carried out on a basis of bulk allocations and priority lists provided by the Director-General of Military Aeronautics. From this time the duties of the Inspection Department in the matter of allocation were confined to notifying the Supply Branch when the machines passed final inspection and were ready for distribution. The control assumed towards the end of 1916 by the Supply Branch over essential materials and components led to further demands on the Inspection Department for the organisation of inspection at foundries and mills.

The system of inspection was developed gradually from experience gained as to the sources of possible failure, delay and wastage of material. The shortage of material soon emphasised the importance of a rigid inspection of materials. When the Inspection Department moved to London, a Materials Branch was set up to control the inspection of materials, but it was soon found necessary to merge this branch once more in the Engine and Aeroplane Branches, and the Engine Branch became responsible for inspection of all metallic materials, while the Aeroplane Branch undertook the examination of all non-metallic substances required in the construction of aircraft.

Until the beginning of 1915 all machines were sent to Farnborough for erection and flight tests. As output increased this led to delay and congestion, and from March, 1915, machines were delivered by contractors to certain specified aerodromes generally near the works, and, after erection by the firm's own staff, were handed over for test to the pilots of the Inspection Department. In the course of tuning-up and flight tests, additional instruments had to be fitted and much experimental work was carried out with regard to carburation, petrol systems and cooling arrangements. These results were embodied in

subsequent specifications, while the inspection staff often induced contractors to make the improvement immediately. To provide the numerous small spares involved in these modifications and to replace the considerable wastage which took place at this period, even in the course of flight test, stores were drawn by the Aeronautical Inspection Department from the Ordnance Aircraft Stores Depôts on direct indent, the parts being vouchered and written off, so far as the Aeronautical Inspection Department was concerned, by notifying the depôt of the contract number of the machine or engine for which the parts were required.

In January, 1915, a scheme of co-operative aircraft construction was established in Scotland with Messrs. G. and J. Weir as the central firm. To provide immediate control of inspection, a separate " Branch Headquarters " was set up in Glasgow under an assistant inspector, as the central local authority for aeronautical inspection in Scotland, acting under the general supervision of main headquarters. This arrangement was the basis of the eventual decentralisation of the work of the department into district control, which was later carried out very extensively. It was found quite impossible for the inspection officers at headquarters to keep in such immediate touch with the ever-changing conditions in the contractor's works, as to be able to deal with urgent questions without causing undue delay. Moreover, by the end of 1915 the staff of the department had increased so greatly that a localised form of control became essential.

During the summer of 1915 the institution of local centres similar to that in Scotland was effected in Coventry, Manchester and London, and the process continued until by November, 1916, the whole of Great Britain was divided into convenient areas. This system was later extended to Ireland, which became a district of itself. Each of the centres controlled a territory with definite boundaries. This method was applied both in aeroplane and engine production, but the aeroplane and engine districts were quite distinct. The closest co-operation was essential between district officers, to prevent different standards of workmanship and test requirements in the different areas. The first inspection bond was established in connection with the Ordnance Aircraft Department Stores at Farnborough, which came into being at the beginning of the war. These stores were subsequently removed to Milton, in Berkshire, whither the inspection bond accompanied it. A second inspection bond was established late in 1915 at the Royal Flying Corps Stores at Greenwich, dealing with a large variety of accessories, equipment, instruments, etc. This depôt and inspection bond were later moved to Kidbrooke.

During the period when district control was being instituted, the extensive use of female viewers was developed. Women had been employed in this capacity early in 1915 at the Ordnance Aircraft Department Stores, Farnborough. It may be claimed for the Aeronautical Inspection Department that it was the pioneer of inspection by women, and it is certain that without the extraordinary keenness, energy and ability shown by the women staff in their work, the efficiency

of the department's inspection would have been diminished to a serious degree, since the man-power available for inspection was in no way comparable with the increase in work. From this time onwards to the end of the war, not less than 50 per cent. of the whole Inspection Department's staff were women. They were trained to undertake more responsible and technical work as time went on, but the bulk of their work was confined to detailed viewing "to drawing," no discretion for the acceptance of parts outside the drawing dimensions being allowed. This function was exercised by the male examiner in charge of the view room, who further periodically checked the work of the viewers, and particularly the parts rejected by them.

In order to reduce as far as possible the volume of inspection at main contractors' works, and to prevent wastage of material and unnecessary transport of unserviceable goods, inspection was instituted at the works of firms producing materials or components on sub-contract orders for the main contractor. Triplicate copies of all the main contractor's sub-contract orders were supplied to the local examiner, who kept one copy for record purposes and despatched the other two to headquarters, where one was kept and the other issued to the examiner or station officer to whom the inspection at the sub-contractor's works was delegated. At the same time a system of release notes was inaugurated, whereby all consignments of approved parts delivered by a sub-contractor to a main contractor were accompanied by a voucher identifying the consignment with its approval; so that on arrival at the main contractor's works the resident examiner was able to pass the whole consignment into the firm's store without re-examination, apart from a superficial inspection to see that the goods had not suffered damage or deterioration in transit. At the same time it was definitely laid down that the Aeronautical Inspection Department's approval at a sub-contractor's works was provisional only, so that parts might be subsequently rejected during the process of incorporation at the main contractor's works. This proviso was found necessary owing to the ever-increasing number of types of engines and aeroplanes and the different requirements regarding dimensions, workmanship, etc., involved in each of the types. In some cases it was only after the production of a considerable number of new machines or engines that the special, and often quite unexpected, requirements of the type were discovered, while, in the meantime, considerable deliveries had been accepted by the Inspection Department at the sub-contractor's works. Naturally, charges of inconsistency were brought against the department, but as a rule the difficulty was overcome by the introduction on the sub-contract order of the clause "subject to A.I.D. inspection at your works, and final A.I.D. approval at our works," the contingency of a percentage acceptance and subsequent rejection being included in the financial arrangements between the contractor and his supplier.

This system of sub-contract inspection, though it certainly presented many difficulties involving the department in much labour and cost, and demanded an increased establishment, undoubtedly fulfilled its purpose, in that it reduced to a minimum the production

of unserviceable parts by sub-contractors owing to lack of experience or incorrectness of workshop practice, and minimised the dislocation at main contractors' works, which might have ensued owing to unexpected rejection of consignments of "key" parts on delivery from sub-contractors.

The general methods of the Aeronautical Inspection Department applied equally to the Aeroplane and Engine Branches, but certain modifications were required in engine inspection owing to the greater complexity of the problem. On the outbreak of war the Engine Inspection Branch was entirely inexperienced, owing to the fact that very few British manufacturers were engaged on aero-engine work. The aero-engine competition initiated by the Government in the early summer of 1914 had been of value to members of the embryo Engine Inspection Branch, since they had been appointed as official observers of the trials. The Aeronautical Inspection Department's staff at the British engine firms consisted of one or two examiners whose duties were the observation of the actual bench tests and the subsequent examination of parts. The records of horse-power, fuel consumption, etc., for every engine, were forwarded to headquarters, and formed a basis for a complete record of deliveries and movements outside the Service itself.

Early in 1915 contracts were placed with five firms for the manufacture of the R.A.F. 1*a*, an 8-cylinder air-cooled engine, and it was stipulated that the spares produced at any one of these factories should be interchangeable with the engines of the other producers. The closest detailed viewing of every part was found necessary, and special sets of master gauges and templates were required to ensure interchangeability. The Inspection Department's staff had to be considerably increased and view rooms organised.

All questions, other than those of a purely routine nature, were discussed direct between the contractors themselves and Aeronautical Inspection Department headquarters, whose officers frequently visited the contractors not only for the purpose of inspection and supervision of the Aeronautical Inspection Department staff, but as representatives of the Military Aeronautics Department. This close link with the Military Aeronautics Branches was further strengthened on the removal to Albemarle Street. Use was also made of the rapidly accumulating experience of the engine repair shops in France partly by means of a transfer of *personnel*.

The removal of headquarters to Adastral House afforded an opportunity for reorganising the headquarters of the Engine Branch, so that instead of the whole of the technical and administrative work of the branch being shared by three or four members, separate sections were set up, dealing with design, construction, repair, installation and *personnel*, leaving the head of the branch free to organise for the future. The Design Section dealt with all technical questions referred to the Aeronautical Inspection Department by the Military Aeronautics Department and contractors apart from questions of inspection, and kept in touch with the service regarding new requirements. They also investigated new designs submitted by inventors and recommended

the placing of experimental orders. The Construction Section provided technical direction and instructions to outstation staff, and arbitrated between outstation staff and contractors. They investigated the effect of modifications required in production engines and prepared for their promulgation by the Directorate of Military Aeronautics, devised appropriate means of testing and checking new methods of construction and design, indicated the proper distribution of the limited stock of inspection apparatus, and collaborated with the materials branch in their testing procedure.

The Engine Repair and Magneto Section supervised the inspection of engines returned from service to contractors for repair. This section was placed in charge of an officer transferred from the R.F.C. Engine Repair Shops, Pont de l'Arche, in order to secure liaison between that depôt and home contractors engaged on similar work. Since this officer had had exceptional experience in testing magnetos, the supervision of magneto manufacture and inspection was vested in this section.

The Engine Installation Section was in charge of engine examiners and mechanics stationed at Aeronautical Inspection Department aerodromes, to inspect all engine installation in machines, and to supervise flight tests so far as engine tuning and performance were concerned. It was also the duty of this section to keep in close touch with the Service with regard to engine experience, and to keep the construction section informed of any inadequacy in inspection by the works inspection staff as discovered in flight tests. The fact that as a rule the engine for which a given machine was designed was not available, so that a different type of engine had to be installed, added considerably to the work of the section.

(*d*) ENGINE SUPPLY.

On the outbreak of war, British firms which were thought to be capable of building either aero-engines or aeroplanes were by arrangement divided between the Army and Navy and allocated to supply the Royal Flying Corps and the Royal Naval Air Service respectively. The Green engine, which was in production before the war, was not found suitable for mounting in an aeroplane and the 120-h.p. Beardmore engine, though manufacture had been started before the war, was not ready for production in quantities for some months. The 90-h.p. R.A.F. which had just emerged from the Royal Aircraft Factory at the outbreak of war, offered the best prospect of production by firms new to the work, since it was the first for which detailed drawings were prepared, but it was not in production until the beginning of 1915. Thus for the first six months of the war, the dependence of the Royal Flying Corps on French engines was complete.

Some account has already been given of the purchases made by the War Department in France.[1] Of the two types of engine used in the early days of the war, the Gnome and Renault, a few were built

[1] See above, p. 42.

in England, but the majority were manufactured in France. When, in the spring of 1915, it became evident that the development of the French Air Service would make French supplies inadequate to meet the demands of both countries, steps were taken by the War Department to arrange for the construction of engines of French design in England. By the middle of 1916 all such engines then in use were being built in this country. Before the manufacture of the Hispano-Suiza engine could be begun in England, protracted negotiations were necessary with the Spanish patentees at Barcelona.[1] The right to build Clerget engines was acquired by an English firm by direct negotiation with the French inventors, but, as in the case of other proprietary engines and machines, there were various difficulties relating to patents and royalties to be cleared up before construction could be begun.[2]

By the end of May, 1915, the Directorate of Military Aeronautics was employing 12, and in December, 1916, 26 English firms as aero-engine builders. Most of them had previous knowledge of car engine manufacture, but an aero-engine differs from other types in many important respects, and much experimental work and modification of tools was necessary before output could be obtained in any quantities.

One of the principal difficulties which beset the Directorate of Military Aeronautics at the end of 1915, when improvement in aeroplane performance became imperative, was the lack of high-powered engines. On the outbreak of war, nearly all the high-powered engines in existence, or being designed, were allocated to the Navy, since such engines are essential for seaplane development. The Director-General of Military Aeronautics had realised before the war that more powerful engines would be required for the land service, and the results of the engine competition held in the spring of 1914 had led him to believe that their development could safely be left to private enterprise; but high-powered engines of British design did not actually become available until the middle of 1916. The engine problem was well on the way to solution before the War Department handed over supplies to the Ministry of Munitions, and the majority of the engines then supplied were of British make. On 1 March, 1917, there was, in fact, an apparent surplus of engines, although certain types (*e.g.* the 90 R.A.F. and the 110 Le Rhone) were heavily in arrears.[3] This difficulty of balancing the type of engine with the class of aeroplane was one of the chief limiting factors in supply throughout the war.

(*e*) Aeroplane Supply.

In August, 1914, there were about 8 British contractors building aeroplanes.[4] The construction of an aeroplane is a much less expensive and complicated undertaking than that of an aero-engine, and pioneer firms had embarked upon this venture, though firms were less ready to take the risk of pioneer work on aero-engines. By June, 1915, there

[1] C.R.F.C. 1868/6 Q, 7 Q.
[2] For royalties on French engines see A.S. 23655/1917.
[3] Hist. Rec./R/1964/3.
[4] *Final Report of the Committee on the Administration and Command of the Royal Flying Corps*, 1916.

were over 30 contractors engaged on aeroplane construction, while the number of sub-contractors ran into several hundreds. Early in 1915, Messrs. G. & J. Weir organised a system of utilising small contractors for the manufacture of aeroplane parts in conjunction with assembly facilities for complete aeroplanes at their own works in the west of Scotland.[1] Many of these firms had, before the war, been engaged in the manufacture of furniture, pianos and woodwork of various kinds. Their employment on aeroplanes was only made possible by supplying them with very detailed drawings and subjecting their work at every stage to a very rigid inspection. At the beginning of the war, the only detailed drawings in existence were those of machines of Royal Aircraft Factory design prepared at the Factory. Private aeroplane makers had not generally paid much attention to the subject of drawings, as all their aeroplanes were built in their own workshops, and modified from time to time as construction progressed. It thus happened that a considerable number of Factory designed machines was ordered at the beginning of the war. The employment of firms outside the trade had the additional advantage that for the first few months of the war the placing of contracts by competitive tender was still possible. This preponderance of Factory designs was natural, in fact inevitable, but in the summer of 1915 a sudden and very rapid development took place in the use of aircraft for war purposes. Machines were required in greater diversity of type, as well as in larger numbers. As has been seen above, German machines of high performance were appearing at the front, and it was clear that every encouragement should be given to designs from any quarter. The G.O.C.R.A.F. called a conference of the trade in October, 1915, and steps were taken to co-ordinate and improve design. Tabulated statements of requirements and, later, definite demands as to performance were issued from time to time to designing firms, who otherwise had a free hand in the mode of development. From the beginning the aeroplane had to be designed round the engine, owing to the few engine types available, and it was frequently found that privately designed machines required engines which could not be supplied.

Until comparatively late in the war, aeroplanes as well as engines were obtained in large numbers from France. Several squadrons were equipped entirely with French machines, *e.g.*, Moranes, Nieuports and Spads.

As mentioned above, it was possible in the early days of the war to call for competitive tenders for aeroplanes, but the placing of cost plus profit contracts for aircraft was started in 1915 as an emergency measure, due to exigencies of the war and the breakdown of the system of competitive tender, since the demand then exceeded the country's capacity for supply. Production was at this time the first consideration and the system of cost and profits contract was the only one by which certain firms could be induced to undertake the work. This type of contract, in which repayment was made of the whole outlay incurred by the firm, together with an agreed percentage as profit, was limited

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[1] See above p. 50.

as far as possible to cases where a contractor took on either work new to him and different from his normal trade, or to new designs in the production of which neither the department nor the contractor had any experience. In both cases the necessity for rearranging shops, installing new machinery and training workmen, together with the general difficulties inseparable from starting a new trade, made it inevitable that the final cost should be higher than the price paid to firms who already knew the work. Some control over expenditure was exercised by the production officers stationed at the works, in that supervision minimised scrappage and waste, but as both they and the contractors were chiefly interested in securing output, economy took a second place, and this type of contract was found to be very costly. The estimation of cost was a very difficult matter, for the firms rarely kept separate accounts for each contract and ran the materials for their various contracts together, so that the accountants engaged by the Department to investigate the cost of any particular contract often had an impossible task. Some check on cost was provided by manufacturing experience at the Royal Aircraft Factory, and there was a small estimating staff attached to the supply department to calculate cost by means of list prices. They provided the contracts section with approximate prices, but a certain elasticity had to be allowed to cover contingencies arising out of the urgency of supplies. For instance, it was sometimes necessary in special cases to do work by hand instead of by machinery.[1] In spite of arrangements for the interchange of information between the Admiralty and the War Office, differences in prices paid sometimes occurred owing to such circumstances as the urgency of particular orders, conditions of inspection, and the circumstances of the firm at the time.

The complicated nature of engine and aeroplane manufacture made their supply the joint production of many trades. Throughout the period during which the War Department undertook supply, contractors were to a great extent left to make their own arrangements for the supply of component parts. By the end of 1916 this system had led to an inordinate amount of sub-contracting and the main contractors often placed their sub-contracts without any regard to the capacity of the sub-contracting firm to produce the required article. In fact, the sub-contractors were in many cases mere agents, who again sublet the work. Delays due to the inability of the main contractors to obtain sub-contract deliveries became very frequent, particularly in the case of small parts such as bolts, nuts and turnbuckles, and action from headquarters became necessary. Large War Department covering orders were placed with all large manufacturers of these components, and main contractors were supplied through the Aircraft Equipment Department. By this means manufacturers of components were enabled to keep their machines running constantly on certain sizes of bolts, etc., and the activities of agents were suppressed.[2] This system of control was largely extended during the closing years of the war, as will be seen hereafter.

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[1] 87/Contracts/84. [2] 87/Contracts/98.

This was a radical change in War Department methods of supply and entailed the necessity of new methods of accounting. The peace-time method was based upon the delivery of goods from a contractor to a depôt. There were two copies of an advice note, one of which was retained by the depôt which inspected and received the goods, the other being returned to the contractor. All bills were rendered by contractors direct to the R.F.C. depôts, which checked and certified them for payment by the War Department. Most of the detailed checking work was accordingly carried out at the depôt and not at headquarters.[1] As output increased the Service depôts experienced great difficulty in dealing with the increased deliveries and delay arose in the payment of contractors' bills. Towards the end of 1915 production was being delayed on this account owing to the fact that contractors had reached the limits of their credit, while large sums were owed them by the War Office. Arrangements were therefore made to make advances on engine and aeroplane contracts up to 20 per cent. of the value of the contract, to enable manufacturers to buy material, etc. Further advances of 60 per cent. of the value of each machine (or of 80 per cent. in cases where no previous advance had been made) were made after the Inspection Department had certified that the machine or engine was ready for test, the balance being paid on final acceptance. Similar advances on contracts for spares were sometimes made, but were not considered so necessary, as the time which elapsed between the placing of the order and the commencement of deliveries was comparatively short.[2] Early in 1917 contracts for spares were becoming of increasing importance and, in order to make them more acceptable to manufacturers, advances on these contracts—more especially for engine spares, in which the interval between the order and first delivery was sometimes considerable—became more frequent, and were made whenever the contractor so desired.[3]

When it became necessary to assist contractors by supplying them with components and materials, a new form of delivery arose, that from one contractor to another, and the system of advice notes, based on the original form of delivery, broke down. Depôts were ignorant of the movement of material and components, and delivery direct to sub-contractors of materials, for which recovery had eventually to be made from the main contractors, still further complicated matters. The War Department had no machinery to cope with the situation. The change was a radical one, involving not only contractors and the Service depôts, but the organisation of headquarters at the War Office, as distinct from the Directorate of Military Aeronautics, for the accounts for aircraft contracts were dealt with in the Finance Sub-Division of the Master-General of Ordnance's Department, and no effective means of dealing with the situation had been evolved when the Ministry of Munitions took over supply.

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[1] HIST. REC./H/1960/2.

[2] M.A./B/45 ; A.S. 24485/1917.

[3] A.S. 24485/1917 ; M.A. 87/Contracts/96.

III. The Position in December, 1916.

Co-ordination between the Admiralty and the War Department with regard to aeronautical supplies was rendered particularly difficult owing to the fundamental differences in the organisation of the two Departments. The one was sub-divided according to the duties performed in regard to the production of material; the other according to the nature of the material to be supplied. The early efforts of the two Departments to secure co-operation have already been described. As time went on, these were increased, and by the end of 1916, they had been supplemented by new methods.

Frequent exchanges, both of aeroplanes and engines, took place between the Services. Up to January, 1917, 308 machines had been transferred by the Admiralty to the Royal Flying Corps, but more than 100 of these were Curtiss planes, which the War Department accepted for auxiliary uses only. The department had placed a small order for these planes in America early in 1916, and an officer of the Aeronautical Inspection Department, with a locally recruited staff, was appointed to assist the Curtiss Company in the production of these machines.[1] They were never used for war purposes but were adopted as training machines in 1917, when the supply from home sources was inadequate. Transferences from the War Department to the Royal Naval Air Service during 1914-16 amounted to 63 aeroplanes, 3 seaplanes and 158 engines, while 61 engines had been handed over by the Admiralty to the Royal Flying Corps.[2]

Many of the best aeroplanes used during the war had their origin during the period 1914-16. The policy adopted by the Admiralty from the beginning, of fostering private enterprise, combined with the sound theory and high standard of excellence provided by Royal Aircraft Factory methods, had established a growing industry capable of assuming entire responsibility for design and all the operations involved in manufacture. The functions required of the technical branches, which succeeded those of the Admiralty and War Department, were to afford guidance as to requirements and assistance with details rather than to originate design. It may fairly be said that the Admiralty and Directorate of Military Aeronautics had laid solidly the foundations of a system of supply, and when consideration is taken of the small nucleus on which they began, their achievements were no less remarkable than those obtained during the last two years of the war. The War Department, starting with about 90 serviceable aeroplanes, had increased the establishment to 1,350 by 31 March, 1916, and on 31 December, 1916, the army establishment of aeroplanes was 3,636 machines.[3]

The Royal Naval Air Service possessed some 70 machines on the outbreak of war. On 31 March, 1916, the available number of their

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[1] Hist. Rec./H/1960/2.

[2] *H.M. Naval Aircraft built, building, and under repair, January,* 1917.

[3] D.M.R.S. 467.

aeroplanes was 340 and of seaplanes 236. On 31 December, 1916, they had 1,086 aeroplanes and 415 seaplanes.[1]

The two organisations were not, however, adapted for the enormous expansion required at the end of 1916. The concentration of responsibility for the Royal Flying Corps and its supplies in one man, though an admirable arrangement when the force was small and the principal characteristics of supply were its urgency and the need for close co-operation between user, designer and manufacturer, must have become an intolerable strain as the service developed. Supply depended entirely on a small staff of enthusiasts, whose methods involved a minimum of formality and routine work, but the growing complexity of supply conditions involved the Department more and more in competition with the Ministry of Munitions, the Admiralty and other Departments, and much of the time of the headquarters staff was consumed in the quest for materials to keep running works which had been built up with so much pains. The system of accounting in both Services was not sufficiently elastic to meet the exigencies of the war, and the inadequacy of the records and statistics proved a drawback, when production was begun on a vast scale.[2] Thus the task before the Ministry of Munitions lay mainly in the direction of building up head-quarters organisation and manufacturing capacity for increased production and of adapting already existing aircraft and engines for mass production, while at the same time modifying them to meet the rapidly changing conditions of warfare.

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[1] D.M.R.S. 467.

[2] D.F. 3/P.A.C./20.

CHAPTER III.

METHODS OF PRODUCTION, 1917-18.

I. Organisation for Supply, Design and Inspection.

(*a*) The Supply Problem, March, 1917.

The transfer of aeronautical supply from the Admiralty and War Department to the Ministry of Munitions in March, 1917, was the largest single addition made to the responsibilities of the Ministry after the period of its inception. The responsibility was one of the heaviest borne by the Ministry, for the transfer synchronised with an enormously increased demand for aviation stores of all descriptions, and difficulties with regard to manufacturing capacity, labour—both skilled and unskilled—machinery and raw materials, which had always been acute, were now increased manifold. The production of a complete aeroplane was now a far more complicated matter than it had been on the outbreak of war, owing to the intricate fittings and equipment required by modern conditions of warfare. The concurrent supply of armament, instruments, bomb gears and sights, engines with all their various components, would have been a complicated matter even had there been no difficulties in the actual supply of the various parts. It is difficult to realise how seriously output could be dislocated by the lack of such things as mica sparking plugs, ball bearings, bolts or turnbuckles, yet it was often these small components which were most difficult to obtain. The aeroplane itself was a comparatively simple structure to manufacture and could be produced to a great extent by unskilled labour, with suitable skilled supervision. The engine was an entirely different matter. Most highly skilled labour was required at every stage of production, and engine output was a limiting factor in aircraft supply throughout the war. Both aircraft and aero-engine manufacture were infant industries in England in 1914. Most of the aircraft firms of 1917 were of quite recent growth, their financial position precarious, their works organisation undeveloped and their equipment small. Special financial arrangements and a most rigid inspection were necessary. The employment of small sub-contracting firms had been pushed to the limits of efficiency, having regard to problems of inspection, allocation of raw material, contracts and finance. Most aero-engine firms did not possess production facilities for output on a large scale, partly owing to the expensive nature of aero-engine development and partly owing to the smallness of orders placed during the early years of the war, these small contracts being due to doubts of the technical merits of the various types of engine. Aeronautical supply was the last large service to impose its claim on industry during the war. It had, therefore, to be content with a comparatively small ratio of skilled labour, though

it actually required an exceptionally large one, and a very large proportion of this skilled labour consisted of young men of military age, whose retention, in the face of the urgent needs of the army for man-power, was a serious matter. The high percentage of unskilled labour which the industry had to absorb handicapped supply in several ways. It made acceleration almost out of the question, and involved abnormal waste due to scrapping and defective work, a very high grade of precision being required, and it necessitated a most elaborate system of jigs and fixtures, at a time when skilled tool-room labour was phenomenally scarce. The problem of skilled labour was further complicated by the fact that the Royal Flying Corps and Royal Naval Air Service were at the same time increasing their establishments and competing for labour of the same type, for their air mechanics, and artisans in engine repair shops, etc. The number of mechanics required for each machine in service has always been high, but the provision of this number constituted a claim on skilled labour equally urgent with the claims of the aircraft firms, since the provision of one without the other would have been useless. The shortage of machine tools was acute before the Ministry of Munitions took over aircraft supply; indeed, this was one of the principal reasons for the transfer. The necessity for providing spare parts, both in aeroplane and engine production, increased the complexity of supply, since it depended on the practically unknown factors of losses and salvage possibilities and entailed facilities approximately equal to those required for the completed article. The great variety of material required in aeroplane construction rendered the supply of materials in itself a difficult problem. Spruce and mahogany had to be imported, and their bulk added to tonnage difficulties. The production of the highest grades of alloy steel in innumerable different qualities involved many metallurgical difficulties, and the ignorance of inexperienced firms as to the heat treatment required for the different grades was a constant source of anxiety to the Inspection Department. The problem of the production of the particular types of optical glass required for gunsights had not yet been solved by British chemists, while linen fabric, tape and glue, and the chemicals used for making dope presented their own problems.

From a technical point of view aircraft as well as its armament and equipment was at an experimental stage. Types had not been standardised and the ordinary manufacturing difficulties were complicated by continual modifications in design, involving waste of material, increased inspection and cost of production and a good deal of unavoidable friction. This difficulty was inseparable from aircraft construction for various reasons. New types of aeroplane and aero-engine could only be developed by actual air experience. Progress could not be stopped while this experience was being gained. Accordingly risks had to be taken which involved the embodiment of modifications concurrent with manufacture, always a great hindrance to bulk production. Further, the widening field of application of aircraft continually set up fresh problems which called for fresh developments of type. Over-standardisation was a danger to be avoided, not only

for the above reasons, but for the far more important considerations of the safety and *morale* of the pilot. The latter depends so greatly upon his faith in his machine, that certain types of improvement had to be adopted at once whatever dislocation of supply might be involved.

The opportunist aerial policy, adopted on account of insufficient supply, itself reacted to complicate supply. The needs of the Services could not be accurately foretold far in advance, manufacturing programmes were at best in the nature of guesses, and the effect of this upon production can be estimated when it is realised that an average of 34 weeks elapsed between the first conception of a new design of aeroplane and its bulk production, while the corresponding time for an aero-engine was 64 weeks. The notice estimated to be necessary for a contractor to change from one type of aeroplane to another was 3½ to 5 months, and from one type of engine to another 6 to 9 months.

To reach the output required to meet the Service demands, priority in capacity, labour, tools and materials were all essential. No special priority had been granted for aeronautical supplies before the Ministry took over supply. Certain priorities existed on paper, but they could not be carried out without disturbing other supplies, more particularly Admiralty supplies, and since Admiralty priority was a tradition with those directing industrial establishments, existing aeronautical priority was quite ineffective.

About the same time that the Ministry had assumed responsibility for aeronautical supply, America declared war on Germany. America's entry into the war had an adverse effect on British aeronautical supply for many months. The Government at Washington completely failed to appreciate the complexity of the problem of aviation supply and experience in Europe, and their natural desire to develop a policy of their own had a most disturbing effect on British contracts in America, and on the supply of raw material, more especially of silver spruce, the only timber which is wholly satisfactory for aeroplane spars. Large orders placed by America in France threatened the completion of British contracts in that country, while both there and in Italy the facilities for aircraft production were not being fully or efficiently utilised. The American programme was, in the light of British experience, most obviously an overestimate, and it was clear that Great Britain would have to rely entirely on her own efforts to carry out the aerial programme for 1917–18.

(*b*) Department of Aeronautical Supplies.

The efficient organisation of aircraft supply presented a problem of extraordinary difficulty in view of the number of industries involved and the diversity of materials required. For the formation of the new department the Ministry of Munitions received from the Admiralty and War Department a staff of approximately 1,200 at headquarters. The staff so transferred, together with a few civilians appointed by

the Ministry of Munitions was placed under the charge of Mr. William Weir, subsequently Sir William Weir and later Lord Weir, who on 24 January, 1917, was appointed by Dr. Addison, at that time Minister of Munitions, as Controller of Aeronautical Supplies. The organisation itself was known as the Department of Aeronautical Supplies. The letter of appointment required Mr. Weir to carry out, as soon as possible, the reorganisation of the existing Army and Navy aircraft supply sections into one complete supply department on the same general lines as other supply departments of the Ministry, with the usual relations to the Finance, Labour, Establishment and other departments of the Ministry. Mr. Weir at the same time became a member of the Air Board, as one of the representatives thereon for the Ministry of Munitions. The other representative of the Ministry on the Board was Mr. Percy Martin, who was appointed Controller of Petrol Engine Supply. He was responsible primarily for the allocation of engine building facilities and for the allocation of contracts in this country. He was also responsible for any increase in facilities required. His duties were essentially advisory, and concerned petrol engines not only for aircraft, but also for mechanical transport and tanks. The organisation which developed under the Controller, who was assisted by three Assistant Controllers, consisted of two Directorates concerned with supply and inspection, and of three attached branches which dealt respectively with contracts, finance and accounts, and establishment matters. The Supply Department was divided into branches dealing respectively with aeroplanes, seaplanes, engines, materials and accessories, and general services, and the Inspection Department into branches dealing with aeroplanes and engines.

It is important to emphasise that the Department of Aeronautical Supplies, from its inception, held a somewhat unique position in the official hierarchy. Its controller was responsible to the Minister of Munitions, but in fact his work brought him more closely in touch with the Air Board and the Air Services. His position developed into one of practical semi-independence midway between the Air Board and the Ministry of Munitions. His counsel, as a member of the Air Board, carried great weight. Production was to a large extent the limiting factor in the activities of the flying services. His work set the pace to the programmes and growth of these services. The rapid development of aeronautics, and the need for very special action in the case of an industry of such recent growth, brought the Controller into the vortex of policy and into contact with the services to an extent unknown to the head of any other supply department of the Ministry. On the other hand the resources of the Ministry of Munitions as to materials and facilities were at his disposal.

Immediately on his appointment the Controller had to decide between the respective merits of the naval and military methods of inspection: *i.e.*, whether an independent inspection department should be maintained or whether inspection should be associated with production, in accordance with Admiralty practice. After careful

consideration he decided to retain an independent inspection department, first because the work had to be carried out by a large number of small firms, and a certain number of large firms whose growth had been mushroom like, whose organisation could not be expected to be very perfect, and whose output would therefore require careful examination, and secondly because a very high standard of quality was required in a machine where all the material is very heavily stressed, on which a valuable pilot's life depends, and on which to a certain extent the *morale* of all pilots depends. The only changes made in Aeronautical Inspection Department methods were to give up the individual inspection of each of the small components in cases where firms themselves possessed a good system of inspection, and to substitute selective examination, and to secure that in each large works the chief inspector should be an officer with a considerable degree of discretionary power. One other change had to be made owing to the separation of the Inspection Department from the flying services. Before the Ministry took over supply, aeroplanes were flown for test purposes in some cases by firms' pilots and in other cases by inspection pilots, but for the future it was arranged that the machine should, after assembly at the contractor's works, be tested by the Aeronautical Inspection Department as regards the rigging; it should then be accepted by the Aeronautical Inspection Department and handed over to an acceptance branch of either Army or Navy, and the Services should be responsible for flight tests. Thus the Ministry possessed no aerodromes nor pilots. It was at once obvious that this severance of the Inspection Department from the actual flying tests of the machines and engines presented a grave danger, in that, by losing touch with the current service requirements and conditions, its inspection might develop on the wrong lines, the experience as to running and service defects which had previously been available for the improvement and development of inspection at contractors' works being absent under the new arrangement. The conditions of engine testing which could be applied at works could not reproduce the actual conditions of flight. Atmospheric conditions at service altitudes, which vitally affected carburation, cooling, etc., could obviously not be reproduced commercially at contractors' works. To overcome this difficulty as far as possible and to provide a link between the Services and the Supply and Inspection Departments, a system of liaison between the Aeronautical Inspection Department and the Aircraft Acceptance Parks was instituted, whereby officers of the Aeronautical Inspection Department were deputed to visit periodically all acceptance parks to ascertain from them the defects found in machines and engines in flight and to supply this information to the inspecting staff at contractors' works. This system also served to place at the disposal of the Services the growing experience and knowledge of the department as regards the manufacture and details of newly developed types of aircraft and engines. The Air Board retained responsibility for the design of aircraft and accessories, and formed for this purpose a Technical Department, the staff of which was recruited from the Naval and Military Air Services. It was the duty of this department to

consider and advise the Board on questions of design, and to carry out the experimental work connected therewith. The experimental stations at Grain, Orfordness and Martlesham were under the control of the Air Board.

(c) DEPARTMENT OF AIRCRAFT PRODUCTION.

The beginning of the year 1918 marked an important advance in the organisation of the department. In January of that year, in view of the decision to amalgamate the Royal Naval Air Service and the Royal Flying Corps into one Air Force, the Air Board was raised to the status of a Ministry under a Secretary of State, advised by a Council, Lord Rothermere being the first Secretary of State. At the same time the Technical Department of the Air Board, whose divorce from supply and inspection and consequent subordination to the views of the users had imposed difficulties in the process of production, was transferred to the charge of the Controller of Aeronautical Supplies. The Controller was given the more suitable designation of Director-General of Aircraft Production, the departments under his control being known as the Supply, Technical, Inspection, etc., Departments of Aircraft Production. Sir William Weir, the first Director-General, was appointed a member of the Council of the Ministry of Munitions, and under the constitution of the Air Ministry was also a member of the Air Council. This arrangement gave official recognition to the dual allegiance of the Director-General.

On 1 May, 1918, on the resignation of Lord Rothermere, Sir William Weir was appointed Secretary of State for the Royal Air Force, and was succeeded in the Director-Generalship by Sir Arthur Duckham. The organisation of the Department of Aircraft Production was not materially modified. Perhaps the most profitable innovation was the institution of a weekly meeting of the heads of departments, under the Director-General, at which either the Comptroller-General of Equipment of the Air Ministry or his representative was present. This was an extension of the "Progress and Allocation Meetings" which had been held since the formation of the Aeronautical Supplies Department. A report of the work of departments was circulated prior to, and discussed at, each meeting, and not only were important decisions arrived at round the table, but each controller obtained a valuable perspective of the general position. The tendency to work in watertight compartments that had characterised the earlier administration began to disappear. Further, the Comptroller-General of Equipment, whose requirements the Department of Aircraft Production was created to serve, was brought into direct contact with heads of departments, to the better appreciation of current difficulties.

The Aircraft Production Departments were known in the Ministry of Munitions as the "Air Group" and were presided over by Sir Arthur Duckham, K.C.B., as member of Council A. Seven Controllers were

responsible respectively for departments of Requirements and Review,[1] Technical Questions, Supply and Production, Inspection, Aircraft Finance, Aircraft Contracts, and American Assembly and National Aircraft Factories. In addition C.S.D. (Air), a branch of the Central Stores Department of the Ministry, and Inland Transport (Aircraft), functioning under the Ministry's Transport Department, were attached to the Group.

The Member of Council had the title of Director-General of Aircraft Production in relation to departments, and his functions were to superintend generally the work of the Group, to consider in the first instance all important questions upon which the Controller of a department required assistance or rulings, and either to decide such questions on the Minister's behalf, or refer them to the Minister with a recommendation as to the decision, and to exercise such administrative functions through the Controllers of departments as were necessary to ensure that the policy of the Minister was carried out. Controllers of departments had direct access to the Council Member, and all executive action was taken through them. A supply committee was formed in September, 1917, composed of Controllers of the departments of Aircraft Production. This committee prepared individual requisitions and sanctioned the placing of specific contracts for various types of aeroplanes, engines and seaplanes and the large variety of parts required for maintenance, in accordance with Royal Air Force programmes. It also sanctioned all large purchases of materials and accessories.

The general procedure and functions of departments were carefully worked out and codified by the Aircraft Secretariat, and the following is a rough outline of the salient features of the allocation of functions. The programmes of requirements of the Royal Air Force were considered by the Requirements and Review Department from the standpoint of production. This department maintained records of the progress made in connection with all requisitions, received and issued weekly statements of anticipated and actual deliveries. The Controller acted as Secretary to the Supply Committee and co-ordinated the work involved in carrying out the programmes. As soon as the requisitions had received the sanction of the Requirements Department and the confirmation in certain cases of the Supply Committee, they were forwarded to the Supply and Production Department. This department was composed of branches dealing respectively with aeroplanes, seaplanes, engines, components, materials and accessories, kite balloons, and general services. These branches analysed the requisitions, and prepared detailed specifications to enable contracts to be placed, and with the assistance

[1] This was first formed as a branch of the Department of Aeronautical Supplies, in August, 1917, to consult with the Air Board in the preparation of the programme of requirements, and to maintain records of contracts placed and deliveries made. In June, 1918, the branch was extended to include functions of co-ordination and review of production work. A detailed chart of the internal organisation of the Department of Aircraft Production in November, 1918, appears in Appendix VI.

of local production officers followed up the orders so as to secure deliveries in accordance with the programme. As soon as delivery was effected, a contractor forwarded a signed copy of an advice and inspection note (which operated as a receipt), together with a bill, to the Accounts Department. This department, in addition to the payment of bills, accepted the heavy responsibility of invoicing contractors for goods supplied by the Ministry. The Technical Department sentenced the designs of aeroplanes, aero-engines and components, and also undertook experimental and research work to this end. It was composed of branches known respectively as Design, Applied Design, Experiment and Research, and Armament. These branches controlled the various experimental stations and maintained a large drawing office and a technical publications section. No actual designing work was done by the department, but it reserved to itself initiation of designs to meet specified or contemplated requirements. Merely academic research was discouraged and all experiment and development had definitely military objects. The American Assembly Department was formed to deal with the assembling of American-built Handley Page aeroplanes in the United Kingdom on behalf of the United States Government. Its Controller was also in charge of the National Aircraft Factory Department. This department had charge of ten factories, and the headquarters organisation was made up of branches dealing with finance, labour, buildings and materials. Offices at Paris and Washington were formed in order to co-ordinate the work of production undertaken for the British Government in France and the United States respectively.

Aeronautical supplies, as taken over by the Department in January, 1917, did not include airships, wireless telegraphy, photographic apparatus, aeronautical machine guns, ammunition or bombs, or petrol and oil, but under a special but somewhat irregular arrangement, made to suit the convenience of the Admiralty and War Office, it did include kite-balloons and their accessories. The Department also allocated from among aero-engines under construction certain numbers for supply to the Engineer in Chief of the Navy for rigid and non-rigid airships.

(*d*) PROGRAMME OF SUPPLY.

The difficulties of preparing a supply programme were probably greater in the case of aircraft than for any other munition of war. Not only the weapon, but the services for which it was to be provided were in process of evolution. No finality had been reached as to the number of machines required to equip a squadron. The numbers varied for the type of squadron and even in March, 1918, no definite specification of squadron establishments existed. They had to be adjusted according to requirements at the front. Wastage depended not only on casualties but on the length of life of the machine and varied with every type. The correlation of engine supply to aeroplane supply was very complex, since it varied with the type of engine, and the ratio of supplies of spares to complete machines was also a varying quantity. Repair and salvage possibilities were

most difficult to estimate, yet had a direct bearing on the supply situation. Since the War Department supply had not been based on any programme, no precedent existed as a basis of calculation. At the same time as regarded the larger Service—the Royal Flying Corps—the Supply Department was required to formulate a supply programme on a basis of squadrons, and to preserve sufficient elasticity to allow for changes of policy as to types, often of a very far-reaching character, and involving complete re-equipment of squadrons with a new type of machine. Past experience had shown the necessity for a wide margin to ensure against delays due to technical developments and difficulties, and in the nature of things such delays were likely to increase rather than diminish with an enormously increased programme. These complex conditions reacted upon supply with effects which were not easy to estimate, inasmuch as it was extremely difficult to forecast the exact requirements of specific types of machine sufficiently far ahead to afford manufacturers a proper opportunity of changing from one type to another and of producing one type in sufficient numbers for economic working. Accordingly the problem of programme making was of the nature of a compromise between what was asked for by the Services and what the Supply Department could arrange to produce, modified by the views of the Technical Department as to what class of machine should be produced, and in this way alone were the flying Services enabled to frame their operational programmes on a reliable basis. Though it was difficult to lay down an aeroplane programme for a longer period than six months on account of changes in design, the huge sums of money involved made it most essential that development programmes should be forecast for long periods in advance. It was clearly inadvisable to work up to an enormous output in order to equip a definite number of squadrons by a definite date, only to find that no further development would be required, and that future output would be needed only to make good wastage: or on the other hand to find that, owing to concurrent development of other programmes, the high output could not be maintained on account of difficulties such as shortage of raw material and labour. The uncertainty which prevailed throughout 1917 as to the aerial policy finally to be adopted, intensified the difficulties of programme making. Some surplus over naval and military requirements was to be aimed at, but, until October, supply authorities were ignorant as to the utilisation of this surplus output; in other words they did not know what was the character of the machines which would be required by the Air Service of the future.

The bulky nature of aircraft supplies made it most essential, on account of the storage problem alone, that output should be gradually and progressively increased in order to keep pace with the provision of pilots and the building of aerodromes. Continuity in total output was most important, yet gaps in the output of individual firms were frequent and unavoidable. In framing supply programmes it was the Controller's policy, in order to ensure a proper supply, to assume the continuance of technical difficulties and to arrange a good margin of capacity to cover changes over in design with the contingent gaps in

output. This laid the department open to the charge of over-budgeting entailing the danger of waste when all contracts were in full operation, but the policy was based on the knowledge that it was impossible to achieve concurrent maximum output from all firms at any one period. Moreover, the progressive and rapid development of the Air Force, and the close relation between service and supply officers at the Air Board reduced this danger to a minimum.

Before proceeding to give details as to the supply programmes evolved under these very difficult conditions, it may be well to summarise the figures relating to squadron establishment, wastage and percentage of spares which were used from time to time as a guide in estimating requirements. Under the original organisation of the military wing in 1912 each squadron included 12 aeroplanes. The original squadrons were equipped with a heterogeneous collection of machines as the result of necessity rather than policy. The equipment of each with a single type of machine, suited to the work which the squadron was called on to perform, was aimed at, and by the beginning of 1916 was fairly general. At this time the squadron establishment was being raised to 18 aeroplanes.[1] In September, 1917, the normal squadron establishment was 18 aeroplanes ready for actual service, 6 in reserve, 6 for training purposes, plus an allowance of about 3 machines representing the average number crashed in England during the formation of the squadron. The authorised establishment of the artillery squadrons had been raised in August by an additional 6 machines. By September, 1918, squadron establishments had been fixed as follows:—Reconnaissance 24, fighters 25, twin-engined day bombers 12, single-engine day bombers 18. For night-bombing squadrons the establishment varied with the type of machine used (Handley-Page V-type, 6; H.P. 0·400, 10; FE, etc., 18). Squadrons of large boat seaplanes consisted of 10 machines, and of small boat seaplanes, torpedo aeroplanes and anti-submarine squadrons, 18.[2]

For each squadron about 85 engines had to be provided, the exact number varying from 75 to 100 per squadron, depending on the type of engine. Thus a squadron consisted of 33 machines and an average of 85 engines as the primary establishment, but directly it was sent overseas it became a direct charge on the Supply Department for the maintenance of aeroplane output at the rate of 10 per squadron per month, and of engines at the rate of about 6 per month. The correlation of aeroplane and engine supply was thus very complex, but over a period of 12 months it was approximately 1 aeroplane per engine. The wastage of aeroplanes was found by experience to be greater than that of engines, since after an accident the latter were frequently repairable though the planes themselves were beyond repair, and the reason for the large surplus of engines was the number always in transit between the repair shops and the squadrons. An engine frequently had to be taken out owing to some small defect, and it was necessary to have another ready to take its place.[3] Though the wastage

[1] Mins. of Committee on Administration and Command of Royal Flying Corps, 16th day, 7 July, 1916.

[2] D.M.R.S. 467 P.

[3] Hist. Rec./R/1960/5.

of engines was the same for each type (seven per cent. of equipment per month), rotary engines took longer to repair than stationary air-cooled engines and this type longer than water-cooled, hence the differing numbers of each type required per squadron. The monthly wastage rates on aeroplanes accepted at the beginning of 1918 were :—

66 per cent. on 24 (single-seater fighter).
50 per cent. on 18 (two-seater fighter).
50 per cent. on 24 (corps reconnaissance).
33⅓ per cent. on 18 or 10 bombing machines.

For Home Defence, Middle East and Training squadrons the figure was 20 per cent.[1]

In the middle of 1917 the Supply Department provided spares in equivalent numbers to complete machines and engines produced, but in September, 1918, spares were provided at the rate of about 80 per cent. for engines, 75 per cent. for aeroplanes and 30 per cent. for seaplanes.[2]

At the end of 1916 there were attached to the Expeditionary Force in France 38 squadrons of the Royal Flying Corps and one naval squadron, with 581 machines, ready for action. The total establishment of the Royal Flying Corps was 3,636 machines and 5,701 engines, and the Royal Naval Air Service had 1,086 aeroplanes, 415 seaplanes and 3,344 engines (not including those for airships).[3] Directly the Ministry of Munitions took over supply, an interim programme was prepared of joint naval and military requirements for the four months, March to June, 1917. The approved programme for the Expeditionary Force in France was 66 squadrons, and the total Army requirement for the four months was 4,445 engines and 4,832 aeroplanes. About 3,000 of these were war machines for the Expeditionary Force, about 1,000 for home training, and the balance for overseas and home defence. The Navy required 948 aeroplanes about equally divided between training and war purposes, 724 seaplanes and 1,736 engines. This programme entailed a monthly delivery of 1,436 engines, 1,443 aeroplanes and 181 seaplanes. The average delivery of engines for the two months, January and February, had been 825, and the corresponding figures for aeroplanes and seaplanes were 776 and 15. Against this total requirement of 5,780 aeroplanes, the estimated deliveries for the four months were but 3,721, and against a requirement of 6,181 engines estimated deliveries were 3,396. The actual deliveries for these four months were, however, better than was anticipated. In June, the Government decided that the establishment of the Royal Flying Corps should be extended to 200 Service squadrons, but in view of the possible changes of administration of the Flying Services the programme was not definitely laid down. Between June and August[4] requirements were put forward

[1] A.S. 43215/1918.

[2] *British Munitions Programme, Quarterly Review, September*, 1918. Hist. Rec./R/1000/42. A further account as to spares will be found below, p. 79.

[3] D.M.R.S. 467.

[4] During the 12 months, June 1917–18, no less than five sets of requirements were put forward by the Services, on 17 June, 18 August, 6 October, 25 December, and 21 February. Each entailed some alterations in supply programmes, which have been dealt with only on general lines below.

and a programme arranged on a basis of 132 War Squadrons, giving a total of 86 in France and 46 for other war fields. A corresponding increase had to be made for training. By September, the existing establishment in France was 47 squadrons and in other theatres about 20 squadrons, so that the proposed eventual increase was from 67 to 200 squadrons. The programme arranged in July aimed at a maximum home monthly output of about 2,000 aeroplanes and 1,900 engines to be reached by the beginning of 1918, and a monthly seaplane output of 114 to be reached by November, 1917, while it was hoped that by September, 1918, a total monthly output from all sources of 3,500 aeroplanes and 4,000 engines would be attained. Home sources were relied on entirely for aeroplane output, but a large number of foreign engines were ordered to effect a balance between engine and aeroplane requirements.[1]

The carrying through of this programme depended on adequate supplies of material and labour, and, if attained, provided for the needs of the Navy and the building-up of the increased establishment of the Royal Flying Corps to be achieved at as early a date as other programmes, such as aerodrome building and training of pilots. It also provided by June, 1918, in addition to the 132 squadrons, about 15 fighting squadrons, 9 fast bombing squadrons, and about 300 night bombing aeroplanes carrying heavy loads of bombs.

The provision of engines was the limiting factor in the fulfilment of this programme, and the special measures necessary for dealing with this problem will be detailed below. The chief limiting factor in aeroplane output was the supply of materials, the quantities of timber, chemicals and linen fabric required being very large. The supply of components such as aeronautical general supplies, gun interrupter gear and instruments, was also a difficult problem, and the methods applied in solution are the subject of a separate chapter.[2] The seaplane programme asked for by the Admiralty, though small compared to the aeroplane programme, yet represented an increase quite comparable with it. The principal difficulty in arranging to meet it was the technical situation. Satisfactory types had not been developed, and the technical position was such that the selection of a small number of types from the numerous partially developed ones was almost impossible, while complete sets of working drawings were non-existent.

By October, it was found that the monthly output of 2,000 aeroplanes would not be reached by the end of 1917. From this time short-dated estimates of production were prepared monthly on contracts placed or provisionally settled, so that the monthly figures of estimated output varied, but the final output of 4,000 engines per month, complete with spares, by September, 1918, was still aimed at. This figure had been based on a home production of 3,000 and deliveries from France and America of 500 each, but by December it appeared that the figure would have to be reduced unless further steps were taken to increase home output. The French had intimated

[1] HIST. REC./R/1000/42. [2] See below, Chap. IV.

that deliveries from them must not be relied on after the fulfilment of existing contracts, and in view of this fact and of the uncertainty regarding deliveries from America, the Controller proposed to lay down a scheme for an additional home output to reach 200 engines monthly in August and 500 in October. The ultimate home output was therefore to be 3,200 in August and September, rising to 3,500 in October, and if by that date foreign production was eliminated the maximum output would be 3,500 instead of the 4,000 originally fixed.

Throughout this year, since increased output was the main consideration, the policy adopted had been to produce those types most readily manufactured. As far as design was concerned, 1917 had been a year of compromise. Requirements as to performance and equipment had increased with such rapidity that progress had been concentrated on development and improvement of such machines as had been in production at the beginning of the year. At the end of 1917 an effort was made to consolidate the requirements of the forces in the field and to draw up a consistent programme of design.

In November, 1917, Sir Douglas Haig presented a programme of requirements extending to the summer of 1919. It included a total of 113 squadrons with the Expeditionary Force in France and Italy, in addition to 66 squadrons to form the equipment of an Independent Air Force for long-distance bombing operations against Germany. This involved the provision of 22,016 engines for the period January to June, 1918, and 16,919 aeroplanes and seaplanes for the same period. The corresponding figures for the six-monthly periods July to December and January to June, 1919, were engines, 24,048 and 25,491, and aeroplanes and seaplanes, 21,102 and 25,765. These numbers covered requirements for the maintenance of existing squadrons, replacement of obsolescent machines and engines, equipment of new squadrons, wastage, training and the requisite reserve. Specifications of the performance required for the different types of machine were drawn up and formed the basis of the Royal Air Force types which were introduced to service in the course of the following year. The programme involved the necessity for replacing all existing types by others either not in existence or in the design stage.

With regard to aeroplanes, apart from training machines, no particular difficulty was foreseen in meeting the requirements, subject to certain reservations in connection with the dates at which multiple-engine types were required, and the number of such involved in relation to the whole programme. There was a shortage of training machines during the early months, due to the discontinuance of D.H.6 and the Sopwith Scout, but by the end of the year it appeared that requirements would be met. The demand for engines was not so easy to meet. The requirement for the first six-monthly period covered an increase of 4,000 engines over previous demands, and the programme involved the entire replacement of almost all types then in use. This raised the question of the disposal of superseded types which would still have aviation value, but for the use of which no provision had been made. In short, though the total number of engines which could be

provided was approximately equal to the total demanded, the types did not in all cases meet the requirements of the Services. This partly arose from the fact that supplies had to be supplemented by imported engines, which were necessarily of the types produced in the country of origin, since the policy of having British engines built abroad had not been justified by experience.

Before the end of March a development programme for the whole Air Force, covering 1918, had been agreed between the Comptroller-General of Equipment, the Chief of Air Staff and the Director-General of Aircraft Production. This was a compromise between the demands of the Service and the possibilities of supply. The programme of training machines and engines had been entirely reconstructed. The Avro machine, fitted with 100-h.p. Mono engine, or alternatively 110-h.p. Le Rhone and 130-h.p. Clerget, had been asked for, but it was impossible to fill the whole programme with Avros, and D.H.6 and Sopwith Pup had to be substituted temporarily, while for training engines the surplus over war requirements of other types had to be used. The total number of Service squadrons to be provided under this scheme by January, 1919, was 414. In asking sanction of the Air Council for this scheme it was pointed out that a certain margin had been allowed for alteration of types, etc., but that variations in the programme entailing increased numbers of twin, or multiple-engined machines would make it difficult if not impossible to maintain the required output in number of aeroplanes per month, as such machines involved vastly increased capacity: that any alteration in the training programme, which extended over a long period and was very comprehensive in character, would have a serious effect: that it was becoming difficult to maintain programmes of such dimensions with any degree of elasticity and it would be necessary almost immediately to lay out the extension of the programme to June, 1919. This could only be done by assuming technical progress in new types, and to give any intelligent idea of what was involved in the programme in regard to actual numbers of machines and engines, the basis of squadron establishments and the wastage rates allowed should be specified. This programme was sanctioned by the Air Council as a squadron development programme, and the Comptroller-General of Equipment was empowered by this sanction to give orders for the machines and engines to cover the programme. Some exception was taken to this procedure, but it was recognised that the programme submitted amounted to a policy of insurance and did not in fact exceed what had already been sanctioned by the Cabinet.

This programme, with some modifications due to more recent requirements, held the field until the beginning of June, 1918. It was then found that engine production was considerably short of requirements, and that by the end of the year the shortage on some types would be very serious. The deficit in aeroplanes was not so great, except in training machines. Some shortage had been foreseen. The failure of cypress timber as a substitute for spruce accounted for approximately half the shortage and the position was particularly unfortunate owing to the fact that there was a large surplus of engines

for these machines. In seaplanes there was a shortage on almost every type, due in large measure to requirements having been increased in February, and new facilities not having had time to start production. In addition, the uncertainty with regard to types had caused so much delay that maximum production from facilities available had never been possible. The effect of this situation on the actual formation of squadrons was not so serious as might have been expected, the actual shortage of squadrons on a total programme of 125 being only seven, and the shortage with the Expeditionary Force in France being five on a total of 91. In many cases, however, the squadrons were not supplied with the type of machine for which they had asked, the worst cases being those of the Corps Reconnaissance Bristol Fighter (Arab), of which no squadron was forthcoming owing to the situation of the Arab engine, and the A.W., with 160-h.p. Beardmore, was substituted. The bomber D.H.9 was also four squadrons short owing to the shortage of B.H.P. engines, but it was hoped that additional Liberties would put this right.

A Royal Air Force programme to 30 June, 1919, was considered by supply departments in September, and a provisional supply programme to 30 September, 1919, based on the possibilities of engine supply, was put forward to meet it. It aimed at the maintenance in the field of 328 squadrons. The limiting factors in providing for this establishment were engines and man-power, and the latter problem was the more formidable. There were at that time 92 squadrons with the Expeditionary Force in France with an establishment of 1,838 machines, and the programme allowed for an increase by September, 1919, to 155 squadrons, involving 2,940 machines. A programme was laid down, providing for an output of 3,200 aeroplanes and about 4,800 engines, complete with spares, monthly until September, 1919,[1] but since the Armistice prevented the carrying out of this programme it is unnecessary to enter into details of its construction.

From the time when aircraft supplies were taken over from the Services, the Supply Department was much handicapped by the lack of accurate statistics. An approximate estimate of requirements was made out for the programme March to June, 1917, but as the data available were incomplete and in many cases unreliable, the figures were a guess rather than an estimate. A special branch was therefore set up for dealing with raw material requirements under a Director of Requirements and Statistics. As regards aeroplanes, seaplanes and engines, an approximate idea of the position was obtained, but with regard to spares, accessories, etc., it was impossible to find what contracts had been placed or what was the position of any part with regard to supply. It was therefore arranged that a copy of the A.S.1 form, which had been instituted by the Accounts Branch as a means of tracing deliveries, should be addressed direct to the statistical branch, thus enabling record to be made of deliveries against all contracts,

[1] Hist. Rec./R/1000/42.

and providing a means of informing supply branches as to the exact position of supplies. Programmes of requirements of material, etc., were not submitted for sanction, as approval of supply programmes was taken to cover all material, components and spares required, but as guns and ammunition were supplied by the War Office for the Royal Flying Corps and by the Admiralty for the Royal Naval Air Service, special programmes were prepared by the Services and forwarded direct without reference to the Air Board.

II. The Engine Situation, 1917-18.

At the end of 1916, the utmost confusion prevailed on account of the number and variety of departments which were making demands on the engine producing capacity of the country. Petrol engines were required for aircraft, tanks, mechanical transport, for agricultural machinery and many other purposes apart from naval and marine service, so that competition was rife, both within the Ministry and between it and other Departments. The question of centralising the supply of engines was referred to the same Advisory Committee of the Ministry which was considering at this time the question of centralising aeronautical supply. On the advice of the committee a new department was set up in January, 1917, with Mr. Percy Martin as Controller, to co-ordinate manufacture of petrol engines and to allocate the available supplies among the departments concerned.

In February, 1917, Sir Douglas Haig emphasised the necessity of absolute priority for the Air Services in their requirements of aero-engines,[1] and the early efforts of the new Controller were directed towards the allocation of all available engine building capacity to the use of the Aeronautical Supplies Department.[2] The policy adopted was to develop the capacity of existing engine makers rather than to introduce new ones to the work, and in September, 1917, aero-engines were obtained from twenty-two British firms, previously employed for the War Department and Admiralty, and two small firms introduced to the work since the beginning of the year.[3]

Throughout 1917 the number of types of aero-engines in production was gradually reduced and engine designers were encouraged to concentrate on certain types. The Sunbeam firm especially had in the past dissipated energy in experimenting with a large number of different types. During 1917 they developed the Arab and Maori, and the Rolls-Royce firm had already produced three types. By the autumn of 1917 the Supply Department was ordering on an engine programme of about 13 types.[4] The programme formulated by the Services at the end of 1917 entailed considerable alteration in the engine programme. The service members of the Air Council were of the opinion that it was possible to reduce the engines on service on any fighting front to three types, comprising the Eagle, the Falcon and a rotary engine. The Rolls Royce engines were at that time a fetish among pilots, and were

[1] D.M.R.S. 514.
[2] HIST. REC./R/1920/1; 1964/1.
[3] HIST. REC./R/1960/5.
[4] *Ibid.*

considered infinitely superior to any other engine used in the allied or enemy services. It was, of course, impossible to reduce the engine types to anything like this degree, without long preparation, and the programme as presented by the services included the Hispano-Suiza, 110 Le Rhone, Falcon and Eagle, while the 100 Mono was used for training and the B.R.2 for Snipe aeroplanes and for seaplanes. In stating how far he was able to meet the demands, Lord Weir pointed out that as regarded eventual types the demands called for engines of a character which could not be supplied without dislocating the programme already arranged and imposing an undue strain on the supply of skilled labour. The only method by which the supply of high-powered engines could be secured within the 18 months period was by augmenting our own resources by the provision of Liberty engines from America. Steps were immediately taken to increase the production of the types of engine required, but Lord Weir emphasised the risks incurred in staking too greatly upon certain types.

> "The policy of the past nine months, under which we have obtained as many as possible of types most readily procurable, now permits, to a very large extent, the initiation of a more general standardisation policy, without seriously crippling the growth of establishment. At the same time it must be made perfectly clear that no reason is seen why future experience may not act, as in the past, to modify and limit a standardisation policy."

In particular he took strong exception to the demand for Falcon engines, as the B.H.P. was the better engine to put into production.[1]

Finally, much against the better judgment of the Supply Department, to whom the difficulties inherent in the production of Rolls-Royce engines were not unknown,[2] these engines were given a preponderating position in the 1918 programme. In addition to these, the Hispano-Suiza, B.H.P., B.R.2 and Sunbeam Arab were the engines to be chiefly used, while, as an engine of high power, great reliance was placed on the Liberty engine then being built in America, to meet the needs of the heavy bombing machines. Of these engines, the B.H.P., Rolls-Royce Eagle, and Sunbeam Arab had hardly reached the production stage, and for supplies of the Hispano-Suiza the department was greatly dependent on France. These engines had figured largely in the programme laid down in August, and production on a large scale had already been arranged. Still bigger orders were placed to meet the new demands, the contracts with Rolls-Royce especially being increased, the requirements stated in August being doubled in the new programme.

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1 Hist. Rec./R/1964/3.

2 "Mr. Martin and I are firmly of the opinion that, in view of other designs of engines, better results can be obtained by training existing works and establishing new works to build designs other than the Rolls-Royce, especially when time and quantity are of important consideration."—(*Sir W. Weir*, 3 November, 1917.)

"I do not consider we should increase the production of complicated types."—(*Sir A. Duckham*, 5 November, 1917.)

The dangers of working on too small a programme of types soon began to be evident. The Arab, which had been first run towards the end of 1916, developed numerous defects during flight tests, and innumerable modifications were found necessary. Great difficulty was experienced in obtaining suitable aluminium cylinder castings. Since it was one of the first cases where a type was selected and put into production with a number of manufacturers,[1] the alterations in design were peculiarly unfortunate. The B.H.P. engine also developed marked defects during the process of manufacture. It had been satisfactorily made in small numbers, but when it was determined to place it in full production, the firm to whom the order was given started radical alterations in design which they considered essential in order to obtain bulk production. Much delay was caused in bringing these changes into operation, and experience in flight necessitated still further modifications. It was also found that for bulk production the aluminium cylinder block required a large amount of development and this in itself delayed the programme six months.

As regarded the 200 h.p. Hispano-Suiza, though deliveries of the engines manufactured in England were up to expectations, those of French manufacture arrived in this country in such an inefficient and untested condition, that a large amount of time, labour, material and spare parts had to be supplied and a number of the engines had to await overhaul instead of being put into commission at once. The Aircraft Production Department had no control over the quality of the engines supplied under French contracts, it being a condition insisted upon by the French that the engines should be accepted on French inspection only.[2] This condition of affairs, after lengthy negotiations, was altered and inspection by the Aeronautical Inspection Department at the French factories was instituted.

Still more calamitous was the failure in deliveries of the Rolls-Royce Eagle. In January, 1918, a separate section of the supply branch had been formed under Sir Alfred Herbert to deal with the whole of the Rolls-Royce production. A number of Government establishments were placed at the disposal of this section to be used to assist the Rolls-Royce Company. Among these were Clement Talbot's works (which had been taken over in the previous November),[3] the National Shell Factory, Derby, and a part of the Dudley National Projectile Factory. Part of the capacity of Messrs. White and Poppé and other private firms was similarly placed at the disposal of Messrs. Rolls-Royce. The Supply Department was responsible for providing the sub-contractors and for supplying them with the necessary machine tools, while Messrs. Rolls-Royce were responsible for the supply of jigs and gauges, and placed sub-contracts without reference to the department. They also provided overseers to assist production at the works of sub-contracting firms. The Derby National Shell Factory remained under the Department of Area Organisation as regards financial questions,

[1] See below, Chap. IV.
[2] (Printed) *Weekly Report*, No. 124 VIII (A). 5 January, 1918.
[3] See Vol. VIII, Part II, Chap. VIII.

but in technical matters received instructions from Sir Alfred Herbert, as representing the Department of Aircraft Production. The work allocated to the factory was the manufacture of cylinders, which were provided for the Ministry account at cost price, the price charged to Rolls-Royce being arranged by the Ministry.[1]

The difficulties experienced in regard to the supply of engines during the early part of 1918 increased enormously. The position was still further complicated by the fact that the manufacturing programme, as outlined at that date, was not a very definite one. A weekly output of 200 Eagle and 20 Falcon engines was aimed at, but was never even approximately attained. Great difficulties were experienced in production. The Eagle engine was an uneconomical one to produce owing to its intricate character and the amount of hand-fitting work required. Though the company was given the highest priority for materials and plant, to the prejudice of other engine output, they were unable to make deliveries in any way adequate to meet requirements, and the output of their sub-contractors was disappointing.

A contract with Messrs. Rolls-Royce to supply 1,500 engines from parts manufactured in America, to be erected in this country, was equally disastrous. To provide the additional accommodation required, the works of Messrs. Holmes, in Derby, were taken over and a considerable sum of money was expended in equipping them as assembly shops. Deliveries under this contract should have commenced in February, 1918, but delays occurred in obtaining Treasury sanction for the purchase of machine tools, and owing to this and other disappointments in America no engines had been assembled from these parts up to the time of the Armistice.

Owing to the prominence given to the Eagle engine in the 1918 programme, the failure was extremely serious, and would have been more so had not the Director-General of Aircraft Production recognised at the time that contracts were placed that only half the engines could possibly be produced, and arranged his programme accordingly.[2]

In addition to the failure in these important types of engine, difficulties had to be faced in the supply of ball-bearings, magnetos, piston rings, and interrupter gears, but the main difficulty as regarded components lay in the supply of carburetters. With regard to these the principal difficulty was the backward state of design for carburetters giving good results at high altitudes, but delay had also arisen on account of the difficulty of arranging prices, since it was not sufficiently realised by the authorities responsible that the manufacture of an aero-engine carburetter is a different proposition to the manufacture of a carburetter for a motor-car, and requires much more careful workmanship. The position with regard to stampings was also partly responsible for the serious engine position. The Controller of Forgings and Stampings was unable to provide the necessary stampings

[1] D.A.O./4/959. [2] Hist. Rec./R/1964/3.

to carry out the programme on which the Department of Aircraft Production had been working, and the shortage was due, not to lack of plant, but of labour, and could only be made good by the release of men to put the idle stamps into operation.

Engine production had begun to lag behind aeroplane output towards the end of 1917, and in the spring of 1918 the lack of counterpoise was becoming very serious and was resulting in a large surplus of aeroplanes which had to be stored without engines. It was accentuated by the allocation of such engines as were coming forward, preferentially to squadrons in the field and mobilising, rather than to the Department of Aircraft Production for the purpose of output of aircraft. Further, the number of engines required by the Service for establishment purposes had been increased owing to failure to repair engines in sufficient quantities. In August, 1918, there were more than 4,200 machines in store without engines[1], and on 9 August a sub-committee was appointed by the Director-General of Aircraft Production to report upon the engine situation and suggest remedies. The conclusions reached were that no change in type should be made at any works more frequently than once in 18 months, that modifications should be issued in batches as far as possible, and that aero-engines, their accessories and components, should be given the same priority as had been given to tank engines, especially in the matter of stampings and labour. The sub-committee advised the increased application of the principle of the "parent firm" responsible for the development and organisation for production of engines placed with it, with an attendant group of manufacturers—the firms forming the group to be direct contractors to the Ministry and not sub-contractors to the parent firm.

In order to maintain engines in service a large number of spares was called for, and the manufacture of these spares seriously taxed the engine producing capacity of the country. In the summer of 1917 the shortage of spares had been so serious that a committee was appointed to investigate the subject and secure proper allocation between the Services. Definite schedules were drawn up of spares for each type of aeroplane and engine, together with a fixed ratio of delivery of spares to complete units. This gave the Supply Department a basis on which to work and considerably reduced the large number of urgent demands for parts which were not on contract demand and had to be obtained by special order.[2] It was, however, found later that these spares schedules were too generous in the case of engines. The production of the spares required for six months maintenance and repair of the engines built, consumed a number of machine-man hours almost equivalent to that utilised in the production of the relative engines. The committee advised a reduction in the quantity of spares, either by reducing the number of main parts such as crankcases, crankshafts, cylinder blocks, and connecting rods demanded in the spares schedule, or by eliminating them altogether. The smaller and more rapidly wearing parts could be provided without difficulty.

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[1] M.C. 740.
[2] A.S. 6659/1918.

Some reduction in the number of engines repaired also seemed advisable. Repairs were carried out by the Service at squadron bases and at repair depôts, and since the end of 1917 by civilian contractors at home. During the year ending 30 June, 1918, over 14,000 engines came in for repair, and for the year ending 30 June, 1919, it was estimated that some 30,000 engines would require repair, the monthly requirements running from the existing figure of about 2,000 engines per month up to about 3,500. It was suggested that the number of engines to be repaired should be fixed at 3,000 per month, 2,200 to be dealt with by the Service and the rest at the works of civilian contractors. Any remaining engines should be dismantled to provide supplies of spares. There were several advantages to be gained by placing engines for repairs in service repair shops. Service discipline and control secured immunity from ordinary civilian labour troubles, and would enable the Service to tide over any delays occurring through strikes in civilian worskhops; the work provided opportunities for training service *personnel* and improving their technical knowledge, and the contiguity of the workshops to the front accounted for a considerable reduction in the time during which the engine was out of service. The Service had adopted the principle of concentrating the repair work in individual shops to one type of engine, and this plan was recommended for application in all cases, and certain types of engine were allocated to civilian contractors.[1]

At the repair depôt at Pont de l'Arche certain repairs had since the end of 1917 been carried out by the electric deposit of metal,[2] and arrangements were made for adopting the method in England. Repairs of practically every part, from crankshafts, crankcases and connecting rods downwards, could be made by this method, but the system was open to abuse and lent itself to faking, so that the strictest supervision was necessary. The method could clearly be adapted to rectify new parts which had been wrongly machined and rejected by the Inspection Department. It was applicable to steel, bronze and copper articles, but had not been successfully adapted for aluminium and cast-iron. It was, however, a system which required to be under rigid control and it was not advisable to place it in the hands of contractors. A London engineering firm had been doing repairs by this method for an aero-engine contractor early in 1918, but the Director-General of Aircraft Production had taken control of the process and no such work was allowed without his sanction.[3]

In addition to the engines mentioned above, other types were still being produced throughout 1918. The Engine Sub-Committee recommended a restriction of the number of types and the adoption of certain national types, for which they recommended the 350 h.p. Eagle, 300 h.p. A.B.C. Dragonfly, 500 h.p. Atlantic Puma (Pacific), and 600 h.p. Rolls-Royce Condor, with the addition of the three foreign engines 300 h.p. Hispano-Suiza, 400 h.p. Liberty, and 300 h.p. F.I.A.T., to be obtained in France, America and Italy respectively.

[1] *First Report of Engine Sub-Committee*, 25 September, 1918. (Hist. Rec./R/1964/3.)
[2] (Printed) *Weekly Report* 122, VIII (A). 15 December, 1917.
[3] A.S. 9107/1918.

By the autumn of 1918, it became apparent that supplies both of the 300-h.p. Hispano-Suiza and of the Liberty engine were going to fail. For the big bombers, designed for raiding Germany, the Eagle VIII and the Liberty engine had been principally relied on. About the time of the American entry into the war a commission was sent to the Allied countries to investigate the manufacture of internal-combustion engines. The Rolls-Royce and Loraine-Dietrich were considered the best engines available at that time, but the former was not adapted to American methods of manufacture and the latter had not been fully tried out. It was therefore decided to design a distinctive American engine, the Liberty, developing 200 h.p. with 8 cylinders and 300 h.p. with 12 cylinders. Production was started in August, 1917,[1] and great things were expected of the engine. An order for 3,000 was placed by the Department of Aircraft Production, but by the end of March no deliveries had been made and the authorities in America were asked to send anything from 50 to 100 complete sets of parts for assembly in England. Until July there was great uncertainty as to the American aircraft programme, but hopes were held out that ample supplies would be forthcoming, though only 980 had been allocated to Great Britain. In June, a further request for 2,500 in addition to the 3,000 already on order was made by the department, but in July it was officially intimated that no more than 980 could be spared from the American programme until the end of the year. It was estimated that the total production of Liberty engines for all purposes by the end of December, 1918, would be 16,000. Of these the Americans required 14,000, leaving 2,000 for division between France and Great Britain, whose requirements were 2,500 and 2,433 respectively.[2] In spite of urgent representations which were repeatedly made to the United States authorities, the actual number shipped to England before the Armistice was only 980, and the failure of this engine which was required for the D.H.9a, D.H.10, Handley Page and Vickers bombers, as well as for large boat seaplanes, seriously handicapped the British raiding policy in the summer of 1918. In July, Handley Page machines were coming forward in advance of engines, and output had to be slowed down while storage capacity was being arranged at the American Assembly Factory at Oldham.[3] Similar difficulties with the Liberty engine were experienced by the American authorities.

III. Relations with the Trade.

(a) THE LABOUR PROBLEM.

The problem of supplying labour for the fulfilment of the aircraft programme was not an easy one. Skilled labour for aircraft work, and especially the necessary machine tool makers, had been short before January, 1917. This difficulty was partially met by a special levy of machine tool makers for aeronautical work. This supply was

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[1] *Aeronautical Journal*, March, 1919.
[2] D.M.R.S. 467P; HIST. REC./R/1964/3.
[3] HIST. REC./R/1960/19.

exhausted by June, 1917, but, in spite of the Ministry's efforts to encourage training, the expectation that outstanding demands amounting to 92 tool makers could be met from that time by the natural process of dilution was destined to disappointment. The demand for draughtsmen was also large and the supply nil. The men required were highly skilled mechanical draughtsmen, capable of designing jigs and tools and of calculating stresses and strains. Their number was never large, and it had been depleted by recruiting. The extraordinary shortage was also partly due to the fact that, whereas the remuneration of this class of draughtsman averaged £4 5s. per week, the jig and tool maker could earn anything between £5 10s. and £7; the result was that draughtsmen went to the bench as tool makers and rapidly acquired the requisite skill.[1] This shortage of draughtsmen was eased by the end of the year, but arose again for aero-engine work, and was so acute in October, 1918, that a proposal was under consideration that home units should be "combed out" in order to ascertain whether there were any men with suitable qualifications still with the forces. Production officers were instructed to ascertain whether there were any suitable men with aeroplane firms, who, in view of the over-production of aeroplanes, could possibly be spared, and application was made to the War Cabinet for the release of Grade I men serving overseas.

It was found from time to time that skilled workmen were being used on lesser priority work, or on work inferior to their capacity, and to stimulate the up-grading of mechanics, travelling instructors were sent to the different firms. By June, 1917, the demand for skilled operatives had been reduced from the January figure of 1,081 to 249, but the aircraft programme was ever increasing and with it the demand for facilities in production, and though in the summer of 1917 the labour situation was greatly ameliorated by the arrival in England of mechanics from Australia, in July a further demand for 2,800 skilled mechanics was placed before the Ministry of Munitions. Coppersmiths and sheet-metal workers were specially required, and in June, 1918, the question of the employment of women in this trade was finally settled, the ultimate arrangement being that they should be employed on specified operations at semi-skilled rates. An instructional factory at Highgate had already been at work, and 90 women were trained and ready for distribution.

The increasing rate of dilution of labour necessitated increased use of jigs and gauges, so that the demand for tool makers was never satisfied. Labour priority for aeronautical work remained in a very unsatisfactory state during the summer of 1917, and the low general priority given to aero-engine production became more evident daily, firms with higher priorities being able to withdraw the more highly-skilled labour. A second levy for tool makers, skilled turners and fitters was contemplated in July, but nothing was done, and for the week ending 10 September, against 213 tool makers asked for, only

[1] (Printed) *Weekly Report*, No. 88, IV. 21 April, 1917.

three were obtained. In fact, the material supplied by the Government Instructional Factories showed a tendency to swamp the skilled labour upon which their usefulness depended. An application was made in September through the Ministry of Munitions for the Canadian Government to be approached with a view to supplying a number of skilled mechanics for aircraft work, and the special levy proposed in August took place in October. The anticipated demand for skilled workers to cover November, December and January was 2,000, and arrangements were made to procure additional hands under a further skilled labour levy. Another levy of tool-room hands was found necessary in October, 1918, to meet the demands for aero engine firms. In April men temporarily released from the Colours for duty in aircraft firms had been recalled to their units, and some difficulty was also caused at this time by the voluntary enlistment of operatives engaged on specialist work, and steps had to be taken to prevent this.

Throughout the whole of 1917, while the labour situation was at its most critical stage, the Department of Aeronautical Supplies was constantly disturbed by the threatening of their skilled men with calling up notices. The men were not in all cases actually taken, but the department and the firms were involved in a large amount of correspondence and negotiation to enable them to keep the men, while the effect upon the workers themselves was most disturbing. A revised list of protected occupations issued in May omitted certain subsidiary trades intimately connected with aeronautical output, and special action was necessary to safeguard these interests. The department's difficulties in this respect were much increased by the inability of the General Services Branch to communicate directly with Munitions Area Dilution Officers. All communications had to be made through the Labour Department, and the delay entailed thereby often resulted in men having joined up before any action could be taken to stop them. The position was greatly eased in September owing to the establishment of direct communication between the Aeronautical Supplies Department and recruiting officers and military representatives.

In order to meet the heavy demand for semi-skilled labour for aircraft work, the Training Section of the Ministry of Munitions considerably extended their training facilities and, latterly, had in operation more than 40 schools throughout the country, 15 of these being entirely devoted to aircraft requirements. The chief instructional districts were London, Birmingham, Manchester, Loughborough, and Bristol. In some cases existing factories with their full complement of machine tools were acquired. In others it was necessary to erect suitable buildings and to instal the necessary machinery.[1]

A large programme was required for training moulders and core-makers for aluminium work on Sunbeam engines, and a special training school for aeroplane erectors and fitters became necessary in March, 1917. Women were trained in moulding and core-making and an instructional factory for erectors and fitters was started at Bristol, while a similar establishment was set up at Birmingham for training aero-engine mechanics.

[1] HIST. REC./H/1960/2. See Vol. IV, Part IV, p. 72.

By the end of March, 1917, the Training Section was furnishing from 50 to 60 trained pupils weekly, this being approximately one-third of the ultimate capacity of the aircraft schools. The output of these training schools increased with great rapidity and the excellence of the work produced was an important factor in reconciling the contractors to dilution of labour in their works.[1] Dilution was steadily on the increase. In June, 1917, women and boys under 18 were employed in aircraft work in the following percentages: aeroplane firms, 31 per cent.; aero-engine firms, 29 per cent.; accessories firms, 48 per cent. In 28 representative aircraft firms the total staff on 15 January, 1917, was 23,152 with a dilution percentage (women only) of 19·6. On 15 June, 1917, it was 29,530 with a percentage of 37·5 (women and boys under 18). In October, 1917, the dilution percentage still stood at 37·5 in aircraft firms, and it was considered that the separation of the dilution executive from the supply department tended to prevent the attainment of the best results in this direction, and that if dilution instructions could be issued from the directorates controlling contracts much more rapid advance in dilution could be made. By December, considerable increases in the percentage had been obtained in all aircraft firms, the figures being 40·1, 43·1 and 50·5 for aeroplanes, engines and accessories respectively. In October, 1918, the dilution figure for aircraft construction generally stood at 46 per cent.[2]

In the summer of 1917 the number of employees in protected firms on aeronautical work was 137,209, including 58,142 men of military age, and 41,963 women. Throughout 1918 the number employed increased steadily, and in September, of a total of 202,000 employees 134,900 were males.[3] The training schools supplied a total of 14,834 hands to the aircraft industry for the two years ending October, 1918.

The labour unrest which was prevalent during the whole period 1917–18 was particularly disastrous in the aircraft industry owing to the complex nature of the supply and the urgent necessity for continuity of production. Stocks of material, which in the case of some industries alleviated the effect of a strike, were non-existent in the aircraft industry, and owing to the large and ever-increasing masses of labour employed, inefficiency, which is always associated with discontinuity of production, was specially marked. Throughout 1917 in particular the whole wood-working industry was in a perpetual state of unrest on the subject of the introduction of piecework rates.[4] The policy of the Ministry was to introduce piecework wherever possible, particularly in wood-working trades. This was not so much on account of lack of wood-working labour, as of the necessity for increased exertion to achieve a better output per square foot of floor space. A settlement of rate for wood-workers was reached on

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[1] (Printed) *Weekly Report*, No. 91, VI. 12 May, 1917.
[2] (Printed) *Weekly Reports, passim.* Hist. Rec./H/1960/2.
[3] Vol. VI, Part IV, pp. 53, 55.
[4] See Vol. V, Part II, Chap. VII.

27 October, 1917, but the adjustment of wages and working conditions was somewhat delayed owing to representations from the Admiralty, who feared it would have an unsettling effect on carpenters engaged in ship construction. Further delay was occasioned by opposition on the part of the Engineering Employers' Federation to inclusion in the aircraft agreement of standardised weekly hours and system of overtime payment, which were considered particularly desirable in the case of aircraft workers, and the agreement was not finally issued until 8 February, 1918.

A strike of sheet-metal workers in the winter and spring of 1917-18 had particularly disastrous effects on production. These workers made tanks, cowling, and a number of metal fittings which might be termed "completion items" of aeroplanes, as well as radiators, and the restrictions on dilution in the trade, mentioned above, had already caused some shortage in these components. The effect on the output of D.H.9 and Handley Page machines was specially marked, at a time when the demand for them was particularly urgent.

Labour unrest was specially prevalent in the national factories. This applies particularly in the case of Waddon and Aintree and in a minor degree to Heaton Chapel and Kensington (Clement Talbot's). On the other hand, labour disputes were of rare occurrence at Hayes, Greet and Sudbury, probably for the reason that the Ministry took over the employees of the former owners of these factories, and owing in some degree to the tact and firmness of the managing staffs. At some of the national factories young men holding advanced views on labour questions were introduced, who, after a short period of service, became shop stewards and members of the shop stewards' committees. Apparently also the national factories were regarded as suitable places for the establishment of fresh precedents, as the creation of such would provide strong arguments for their general recognition throughout the country. The trade union officials having been deprived under the Munitions of War Act of the right to organise strikes, the shop stewards gradually acquired more power as the war proceeded.[1] The result was that they very often opposed the executive of their unions if the executive decisions did not coincide with their own views, and they sometimes interpreted agreement between their unions and the employers' federations as they thought fit. This state of things was not by any means confined to the national factories. In some cases an insubordinate, an almost revolutionary spirit, was strongly in evidence. The electricians, employed by the Director of Factory Construction at Waddon and at the Oldham factory for assembling American aircraft, were a constant source of anxiety, and as they were not under the control of the factory management, the latter were powerless to deal with them. As a consequence, the discipline of the factory workers suffered.

As regards the general body of workers, it should in fairness be said that probably 95 per cent. of them were loyal and patriotic and anxious to support in the workshops their comrades in the trenches.

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[1] N.A.F. 42/3/3.

But they were misguided by their leaders in the factories and swayed by professional agitators outside, and were often forced into disaffection and antagonism to the Government against their own interests and their better judgment. It has been suggested that had a firmer hand been kept upon the shop stewards and the strike organisers, and the workers' legitimate grievances dealt with promptly, a good deal of trouble would have been avoided and many of the labour difficulties encountered would never have arisen.[1]

A production bonus was in operation for the workpeople at Heaton Chapel and Aintree. At Waddon, one was sanctioned on 4 October, 1918, for the C.C. gear-shop operatives, and at the date of the Armistice one was about to be authorised for aeroplane workers. At Greet a bonus for good time-keeping was allowed by the previous owners of the factory and was continued by the Ministry. Piece-work was also established at this factory, and appears to have been regarded with considerable favour by the workers. It undoubtedly assisted to increase output without raising unduly the cost of production. The experience gained at this factory goes to show that, under conditions in which it can be applied, piece-work is a satisfactory method of remuneration, from the point of view both of the employer and employed. At Hayes, piece-work was impracticable owing to the varied nature of the work, which included experimental work and the manufacture of aero-engine spares of numerous types. The divergent views held by the factory workpeople on the piece-work question should be noted. The operatives at Waddon "struck" against the introduction of the system, while those at Aintree "struck" for it, against the counsel of their own unions.

(*b*) Contracts and Finance.

The forms of contract usually adopted by the Ministry of Munitions were applied to aeroplanes. The method of fixed prices based on investigation of actual costs at the contractors' works was adopted where possible, but the urgency of supply and the experimental nature of the work made the provisional price contract convenient on many occasions. By this method the order was placed, and the price left open for revision and adjustment before or after the completion of the work. This system necessitated the attachment of technical estimators to the Contracts Branch and the provision of an accountants' costing section. The cost plus percentage type of contract was only used in special cases. By this system the contractor was repaid his actual outlay together with an agreed percentage on the outlay, for profit. Its unsatisfactory nature was recognised, as it provided no incentive to the contractor to keep down cost. The profit-sharing or co-operative contract was far more satisfactory, as giving a direct incentive to economy. In this type all saving below a "standard" price was shared with the Government. The retention of the cost plus profit type was necessary for many contracts, especially those in connection with experimental seaplanes, and was continued until the end of the

[1] Hist. Rec./H/1960/2.

war, but several safeguards were in force to check expenditure under such contracts. Contractors were forbidden to pay wages above district rates; inspectors in some cases checked the amount of material used and there were periodical audits of cost during the progress of the work.[1] In October, 1917, when a rise of 12½ per cent. in the wages of skilled day workers was awarded by the Government,[2] it became necessary to devise some definite method of dealing with the effect of this and similar action on contracts. It was arranged that in all future cost plus profit contracts the percentages covering profit and oncost were to be calculated on rates of wages payable at the time the contract was placed, and subsequent increases in rates of wages would be dealt with separately and met by an extra payment without added percentages.[3] In the case of other contracts a clause was inserted allowing for an increase in prices to meet rises in cost of materials and wages due to Government action. The increase was either agreed between the contractor and the Ministry, or failing agreement, the settlement might be postponed till the completion of the contract, when accounts and figures could be investigated.[4] It was rarely possible to arrange running contracts in aircraft production. Changes in type were so frequent that comparatively small orders were given, and disheartening and costly breaks in production were sometimes caused through delay in placing a new contract or through difficulties in obtaining raw material to carry it out. The running contract was adopted for the production of Rolls-Royce engines and was found of great value in simplifying the provision of material.

The fixing of fair prices for aircraft supplies of all kinds has always been a difficult problem. The pre-war system of obtaining fair prices by competitive tender was not applicable in the changed circumstances brought about by the war. Spare parts, more especially wood and fabric parts, were an exception, as prices were considerably reduced as fresh facilities were found,[5] but, in general, the varying circumstances of each contractor and the facilities he had for the particular work, made any comparison of prices misleading. In the case of aeroplanes each contractor had to be considered individually, but the principle that repeat orders with the same firm were placed at not more than, and if possible less than, the original price was observed with very few exceptions, in spite of constant increases in costs of labour and material. It was almost impossible to lay down any standard practice for estimating prices, owing to the numerous types with varying characteristics and details of manufacture. The nearest approach was based on a figure per lb. of loaded weight. This was found to approximate to an average of 10s. 6d., but it could only be accepted as a rough guide.

At no time was it possible to obtain competitive prices for aero-engine construction. The output required was such, and the available sources of supply so restricted, that firms had to be pressed to undertake the work, adapt their factories and extend their premises and

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[1] D.F. 3/P.A.C./20.
[2] A.S. 37626/1917.
[3] A.S. 39317/1917.
[4] A.S. 6241/1918.
[5] HIST. REC./H/1960/2.

plant. These circumstances rendered the fixing of a fair price very difficult. Full advantage was taken from the first of the power to examine firms' books, numerous cost investigations being carried out by the department's accountants in connection with cost plus profit contracts, with the result that in many cases a reduction was effected on the tender prices. A further step towards obtaining the closest possible prices in engine contracts was taken in August, 1917, when the Contracts Branch took the whole responsibility for price, a duty which had previously been shared by the supply branch as technical advisers. An estimating staff was provided for the various contracts sections and assistance was obtained from the Technical Costs Section of the Ministry.[1] In the majority of cases since that time, unless the Ministry's estimate showed the firm's quotation to be reasonable, prices were only fixed after investigation of the actual cost by technical officers or accountants visiting the firms' works.

A detailed system of costing at the National Aircraft Factories was instituted by the Controller of Factory Audits and Costs in October, 1918, for the purpose of determining the actual manufacturing cost of each unit, component and part. Up to that time no adequate costing system was in operation in the factories. This system would have afforded a reliable basis on which to compare national factory costs with those of private firms. The expense of the system was considered to be no longer justified after the Armistice and it was therefore discontinued.

The financial state of the aircraft industry when the Ministry took over supply was far from satisfactory. A larger proportion of contractors were financially weak in this industry than in the case of any other supplies. This state of affairs is not surprising when consideration is taken of the mushroom-like growth of many of the smaller firms and the large capital required in aeroplane and aero-engine construction. It was estimated that a good firm would turn over their capital in aeroplane construction in three months and in engine construction in four to five months, so that it might be assumed that capital would be turned over three times in a year. The aircraft programme for 1918 amounted in value to about £150,000,000 per annum, so that the working capital required would be about £50,000,000.[2]

The ideal procedure would, no doubt, have been to concentrate help on the large and efficient firms and to eliminate entirely the small mushroom concerns. This was, however, impracticable, since many of the small firms had engineering experience which could not be dispensed with owing to the requirements of production. Some comprehensive scheme was urgently required to relieve contractors of their financial burdens, leaving them free to concentrate all their efforts upon production. A case came under the notice of the Inspection Department in April, 1917, in which output of a firm which was staffed to produce 10 machines per week was only 4 machines. The reasons for this poor output were

[1] A.S. 877/1918; HIST. REC./H/1960/2.
[2] M.C. 216.

mainly financial, for owing to the amount of money outstanding much trouble was experienced in obtaining materials, as the majority of the firm's sub-contractors insisted on cash before delivery. The firm were thus unable to keep their staff fully employed, and the result was slackness in supervision and organisation.[1]

Until the autumn of 1917 the matter was left unsettled. The aircraft builders' case had been before the financial authorities for some time, but no action had been taken. Production on the scale required for the 1918 programme placed a severe strain on the financial resources of all firms engaged in the industry, and in September, 1917, Sir William Weir, in a statement before the Munitions Council Committee on Aeroplanes, made a strong appeal for consideration for the industry. He stated that delay in deciding questions of writing off and depreciation had had a serious influence on aircraft constructors in lessening their enthusiasm. He considered that aircraft and aero-engine builders should receive special and preferential treatment by the Inland Revenue and other financial authorities, since most of these firms started with a very small pre-war standard and had committed themselves very heavily as regarded capital expenditure.[2] He was supported by Sir Arthur Duckham, who maintained that no firm which had wholeheartedly come to the country's assistance should be in a worse financial position by so doing. The pre-war profits of the firms were low and their allowance from excess profits taxation was correspondingly low, while their extensions had been paid for out of revenue.[3] In October a committee of the Munitions Council was appointed to consider what steps should be taken to deal with the delay referred to by Sir William Weir and to consider any financial questions which were, in their opinion, delaying output.[4]

Detailed investigation was made into the assistance given to aircraft firms as to capital expenditure for extensions, into accounts for aeronautical supplies, loans to contractors and the financial standing of firms. The unsatisfactory state of the Accounts Branch as to accommodation and staff seems to have been partly responsible for the situation in regard to finance, which was much complicated by clerical delays in the settlement of bills. In addition to the above-mentioned difficulties, the Accounts Branch had to deal with a very difficult situation due to the different methods of accounting adopted by the Admiralty and War Departments before the amalgamation. Neither method was adequate for dealing with the situation which arose on account of bulk purchases by the Government and subsequent issue of materials and components to contractors. The absence in the formal contracts of the terms of issue of material produced complications with regard to invoicing, and the existence of contracts in which no final prices had been accepted made the payment of bills in connection with them exceedingly difficult. The new Accounts Branch had to evolve a new system of accounting and payment under almost

[1] A.S. 6938/17.
[2] HIST. REC./R/1960/5.
[3] HIST. REC./R/1960/8.
[4] M.C. 216.

impossible conditions, and the immediate effect of the new procedure was to throw upon the headquarters staff the detailed checking work which had previously been done at the depôts. Owing to this and to the rapid growth in the accounting transactions generally, the position in the autumn of 1917 became exceedingly grave.[1] There were, in November, 35,000 bills in hand of a probable total value of £10,000,000, against which possibly £8,500,000 had been paid in the form of advances. Bills could not be dealt with under three months, and by March, 1918, it was estimated that they would be coming in at the rate of 6,000 to 7,000 per week. So serious was the state of affairs that it was suggested—though the suggestion was not adopted—that contractors should be asked to state, as at 1 December, the value of bills rendered and unpaid and the amount advanced against them, and that the difference in their favour should be paid; also that they should be asked to state the value of December-January output and that the value of this should be paid on demand, and that during these two months arrears of bills should be cleared off. The statement was made that advances had been made in the past of which probably 25 per cent. only were supported by inspectors' certificates, the balance on contractors' statements only. However this might be, it was clearly necessary to take a certain degree of risk in regard to payments until the methods of dealing with accounts and bills had been systematised and settlements brought up to date.

Grants in varied forms to meet capital expenditure had been made to firms. Contributions had been made by the Ministry to finance extensions, and Ministry property, in the form of buildings, plant or tools, had been placed in the works of private firms. Extensions financed by firms themselves were entitled under the Munitions of War Act to be paid for in part at least out of excess profits. Such allowances varied up to 100 per cent. The abolition of the munitions levy was followed by the transfer of the decision regarding these allowances from the Ministry to the Board of Inland Revenue. The Munitions Works Board was created in February, 1917, to decide on the necessity of each proposal for new capital expenditure and the extent to which financial assistance should be granted. Extensions were sometimes made for which no equipment was forthcoming. The strictures passed by the Select Committee on National Expenditure in March, 1918,[2] on this arrangement led to a more drastic control over extensions to works. This and the difficulty of getting the release of machine tools were contributing factors to the critical engine situation in 1918.[3]

In spite of the Ministry's policy of supplying extra capacity as far as possible in the form of national factories,[4] it was clear that some form of assistance to firms would have to be continued. In view of the delay arising from the transfer of machinery, the collection of labour

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[1] Hist. Rec./H/1960/2.

[2] *First Report* (of Session 1918) *from Select Committee on National Expenditure*, p. 7.

[3] Hist. Rec./H/1964/3, p. 17.

[4] See below, p. 95.

and the training of staff, it was not practicable or economical to increase the number of national factories unduly, where an advance of capital would enable existing firms to make extensions. It was recognised as desirable that such firms should obtain the maximum amount of financial accommodation by the normal means of advances from banks or by public issues of capital on the market, but it was certain that to a large extent they would be obliged to ask for financial assistance from the Ministry. The Treasury stipulated that advances were to be made only to firms of high reputation and established financial standing, and it was not considered desirable that such advances should be secured by requiring the firms to give debentures, as this might affect their credit and injure their borrowing powers. Floating charges were taken on the companies' assets, or an agreement was made to give a floating charge supported by a personal guarantee of the directors that they would not create without sanction any charge prior to the Government charge on their assets. Treasury sanction was obtained by the Ministry at the end of 1917 to make advances on loan up to 100 per cent. of the firm's capital requirements at a rate of interest of 1 per cent. over bank rate, with a minimum of 5 per cent., or to make free grants up to £10,000 or up to 40 per cent. of a firm's capital requirements, as long as the total sum advanced by way of loan and free grant did not exceed £50,000. Cases not falling within those limits required specific Treasury sanction. The suggestion that Government directors should be placed on the boards of such companies was rejected as tending to involve the Government in responsibility for the successful conduct of the companies' affairs.

As regards difficulties arising from delay in settlement of depreciation or writing off allowances, a committee representing the Treasury, Ministry of Munitions, and Inland Revenue Department was appointed in November, 1917, to consider the question of granting assistance to aircraft contractors to meet their liabilities for excess profits duty and munitions levy. It was agreed that there was no necessity to have a standing Treasury committee to deal with loans to such contractors in cases where money due for payments of excess profits duty had been used for the purpose of extensions of their works. Applications would be placed before the Emergency Standing Committee, which met twice a week at the Treasury to settle all urgent business of the Ministry of Munitions. The Munitions Council Committee satisfied itself that cases submitted to the Munitions Works Board had been adequately and promptly settled, and it was arranged that the Inland Revenue authorities should deal with the settlement of accounts, and if contractors found themselves in difficulties, by reason of having used all available cash for extensions or working capital, application for advances at interest from Ministry funds to meet capital needs and to permit of payments of excess profits duty were considered by the Treasury Emergency Committee.

In addition to these grants to meet capital expenditure there arose the question of advances of working capital to carry out supply contracts and of special "financing" advances to contractors whom it was necessary to support in the interests of production. The need

for such advances was a necessary outcome of the conditions obtaining in the aircraft industry. Apart from any question of capital expenditure, the necessity of providing materials in advance, the restriction of credit by the suppliers of material and the large sums which had consequently to be sunk in material and labour, over a period of at least 12 months before deliveries commenced, made the financing of a large contract for aircraft or engines a task beyond the capacity even of firms with substantial capital. The necessity of extending production had involved the introduction of many firms having the necessary qualifications but little or no liquid capital. Some of them had originally been sub-contractors to large aircraft firms, and the system of direct orders had been started with the express object of increasing competition and reducing the excessive prices charged by the main contractors. Many had developed to an incredible extent in order to carry out contracts running to many hundreds of thousands of pounds, and they could not have carried on for a single week if large advances were not made to them by the Department. In such cases the provision of the requisite capital by a public issue of shares was rarely possible and bankers were seldom willing to loan more than what they considered reasonable against a first charge on the assets, and such loans left any subsequent advance by the Department without satisfactory security.

In addition, contractors were often placed in a weak financial position by causes quite outside their own control, such as delay in output due to alterations of design, cancellation of contracts, or the failure of the department to supply the necessary material or parts. Loans to such firms, both as advances against contracts and as "financing" advances, involved some financial risk, but this was to some extent compensated by the reduction in price. In the great majority of cases these loans took the form of contract advances, free of interest, of 20 per cent. of the contract value and were made for the purpose of financing the contract both as regards capital expenditure and provision of material,[1] repayment being made by proportionate deduction from each invoice.[2] In order to avoid delay, Mr. Churchill desired in December, 1917, that general rules should be laid down governing all but the most exceptional cases, so that the Ministry could deal with advances of all kinds without special reference to the Treasury. In the cases of "financing" advances to unsatisfactory firms involving a risk of loss, the Treasury insisted upon special sanction, but in other cases of advances on working capital, rules were laid down as follows, making special reference to the Treasury unnecessary. In the case of firms financially sound, advances might be made up to 100 per cent. of the sum required for working capital, not exceeding the value of the contract, subject to the payment of interest as in the case of loans for extensions. In the case of firms not financially sound, on contracts already existing, advances might be made up to the total value of contracts, subject to the payment of similar interest and to advances not being unduly in advance of deliveries. For future contracts, advances were authorised up to 20 per cent. of the value of contracts, but not exceeding £50,000.

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[1] A.S. 4031/1918. [2] A.S. 19020/1918.

The method of progress payments by weekly or monthly instalments, which was used so largely in Admiralty contracts, was not approved by the Ministry of Munitions. It tended to cause difficulty in reaching a settlement with the firm, who had nothing to gain by quoting a price and concluding the contract, and in fact often preferred to ascertain the actual cost and thus obtain a certain profit without risk.[1] It was impossible immediately to banish progress payments in some form, especially in the case of seaplane contracts; and a temporary method was adopted, based on payments at certain stages of assembly. In April, 1918, progress payments were stopped both for seaplane and aeroplane contracts and the practice mentioned above of granting advances at interest up to 20 per cent. of the contract value, repayable by deductions from each invoice, was substituted.[2] On cost plus profit contracts payments were made monthly of the outlay on material and wages actually made and from time to time, at the discretion of the Minister, payments were made on account of profit.[3]

It frequently happened that full payment could not at once be made on delivery of the complete machine or engine, and in August, 1918, a definite procedure with regard to payment in such cases was laid down. Eighty per cent. of the contract price was paid on a *pro forma* invoice supported by a certificate of the inspection officer. This invoice might be sent to the Accounts Branch for payment as soon as the goods had left the premises of the contractor under delivery instructions. This payment was called a delivery advance. If a loan had been previously sanctioned, recoverable by deductions of 20 per cent. from invoices, a constructive recovery was effected by limiting the delivery advance to 60 per cent. of the contract price. When the contractor had received the receipt signed by the inspection officer at the receiving depôt, the goods delivered were billed and the balance of 20 per cent. or 40 per cent. paid by the Accounts Branch.[4]

In the summer of 1918 the large contracts placed for D.H.10 and other large machines gave rise to demands for extensions for erecting shops or aerodromes. Railway transport for these machines was often impossible owing to their great span and height, and orders had to be placed only with such firms as had aerodromes attached to or adjacent to their works, or facilities for providing them.[5] This led to increased demands for loans by the Ministry, and cases frequently occurred where companies asked for advances which if treated as ordinary borrowings exceeded the borrowing powers of the directors.[6]

The peculiar financial difficulties of the aircraft industry necessitated special consideration of the break clause to be inserted in aircraft and aero-engine contracts. The length of time required for production, the heavy expenditure incurred in the purchase of raw material and labour, for months before any return was obtained, and the small residual value of the material of the incomplete unit were reasons which necessitated a longer break clause in aircraft

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1 A.S. 26686/1917.
2 *Ibid.*
3 A.S. 5435/1918.
4 A.S. 26686/1917.
5 A.S. 24818/1918; 24926/1918.
6 A.S. 19020/1918.

contracts than was provided in the case of other munitions. In the case of aeroplanes three months' notice, of engines four months' notice, and of spares two months' notice of termination was to be given.[1]

The claims of contractors for royalties on types adopted by the services formed a very difficult and vexed question throughout the war,[2] owing to the very great divergence between the ideas of the contractor and of the departments as to the money value of designs. Many cases were settled after long negotiation on equitable terms, but a fair number remained for adjustment by the Royalties Commission.

A fruitful source of difficulty in supply was the habitual over-estimation by contractors of their capacity for production. They failed to realise the inexperience of the available labour, and of their sub-contractors, and the difficulties associated with the production of the necessary jigs, gauges and tools. This difficulty was so serious in relation to engine spares at the beginning of 1917 that it was suggested that a clause should be inserted to the effect that estimates of deliveries should be based on plant and machinery available at the time of tendering. It was felt, however, that this would exclude many firms whose initial resources were not large, without eliminating speculation, and the only way to get over the difficulty was to form an estimate, through the production and inspection officers, of the firms' capabilities and base estimates of output upon this.[3] Later it was found necessary to exercise closer supervision over sub-contracts, and main contractors were bound, before submitting requests for approval of sub-contracts, to satisfy themselves that the firm could carry out the work without further sub-contracting or additional machine tools or extension to buildings, or if slight additions to plant were necessary, details had to be sent with the request for approval. The supply department then furnished advice, and if necessary suggested a more suitable firm to undertake the sub-contract.[4] In May, 1917, control was taken over wood-working machinery with a view to meeting the growing demand for aircraft construction.[5] In order that the supply department might deal as far as possible with main contractors only, material for all sub-contracts had to be ordered by the main contractor, in cases of materials which were controlled by the department, or the orders for which required authorisation by the department.[6]

IV. National Aircraft and Aero-Engine Factories.

By the summer of 1917 it was becoming apparent that the capacity of already existing manufacturing concerns was becoming exhausted, and to meet the requirement of the aircraft programme, development on new lines was required. The Controller decided to reverse the policy of distributing the work over a very large number of small producers, and to concentrate in large units. Experience in other branches of the Ministry had shown that the most satisfactory

[1] D.M.R.S. 467 G.
[2] A.S. 25607/1917; 22114/1918.
[3] A.S. 4954/1917.
[4] A.S. 35898/1918.
[5] Vol. VIII, Part III, p. 51.
[6] A.S. 35898/1918.

producers of munitions were the large units specially arranged by the Ministry. The tuition work involved by training a large number of small producers was overtaking the supply of inspectors available. Questions of works organisation, assemblage space, finance, and allocation of material also pointed to the superiority of the larger unit. It was, therefore, proposed in the summer of 1917 to arrange for a number of National Aircraft Factories.

Already in January, 1917, this policy had been adopted with regard to engine supply. The Goss Printing Company's factory, at Hayes (Middlesex), had been purchased and carried on as a National Engine Factory, under the management of Messrs. Mitchell, Shaw & Co., Ltd.[1] Under this arrangement the works and plant belonged to the Ministry for the period of the war, with an option to continue for twelve months thereafter, the Ministry providing all the capital required and taking the whole output at cost.[2] In October, 1917, Messrs. Mitchell, Shaw resigned and the establishment was brought under the direct control of the Ministry.[3]

In September, 1917, it was decided to erect three National Aeroplane Factories each with a capacity of 200 medium-sized machines per month. Sanction was obtained for the expenditure of £1,500,000. Sites were chosen at Croydon (Waddon), Liverpool (Aintree) and Richmond, and negotiations begun for the management of the factories by Messrs. Holland, Hannen and Cubitt, Messrs. Cunard and Messrs. Sopwith respectively on lines similar to those of the National Projectile Factories. It was decided that the Croydon factory, in addition to aeroplanes, should produce interrupter gears for machine guns, and the original sum of £500,000 was found inadequate, and a further £250,000 was granted. Messrs. Sopwith eventually decided to remain independent,[4] and a new factory at Heaton Chapel, near Manchester, the erection of which had been begun in the autumn of 1917, was selected for the third national factory, the managing firm being Messrs. Crossley. In January, 1918, the automobile works of Messrs. Clement Talbot, Ltd., at Kensington,[5] were taken over for the repair of Rolls-Royce aero-engines. The works of the Motor Radiator Manufacturing Company at Greet and Sudbury became National Radiator Factories, and the premises of a cinema firm at Finchley (Bohemia, Ltd.), a National Balloon Factory. Two National Timber-drying Kilns were erected at Swindon and Lancing, and managed by the Great Western Railway Company and the London, Brighton and South Coast Railway Company respectively. The original programme for national factories included several other establishments, but they afterwards lapsed into the status of extensions to existing contractors' works.[6]

The first machine from the Croydon Factory passed inspection on 15 March, 1918, 24 weeks from the commencement of building

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1 A.S. 5591/1918.
2 (Printed) *Weekly Report*, No. 84, IV. (17 March, 1917.)
3 A.S. 5591/1918.
4 HIST. REC./R/1960/5.
5 N.A.F. 91/7/1.
6 A.S. 02842/1918.

operations. All the factories were in part operation by April, 1918.[1]

The agreements made with the managers at Croydon, Aintree and Heaton Chapel were on the same general lines. The managers were to superintend the equipment of the factories, to begin manufacture as soon as sufficient plant was erected and to run the factory for continuous production. They were to engage and maintain an adequate staff, employing women wherever possible. They were to use such material as the Minister should provide, but if the whole were not supplied by him they could buy up to the value of £200 without consulting him. Any sub-contract over £200 had to be approved by the Minister. Managers were to be paid every six months 1 per cent. on the value of plant installed during the first year (for the first year only), 1 per cent. of the value of the output of the factory in the preceding six months and, in the case of Waddon, 1½ per cent. on the total value of the interrupter gears produced in the preceding six months, the minimum sum payable being £5,000. The managers were required to have an efficient costing system and manufacturing accounts and balance sheets were to be prepared half yearly. The Heaton Chapel agreement differed from the other two in that the managers were responsible for the supervision of the erection of the factory, and, in addition to the commissions on output, Messrs. Crossley were given 15 per cent. of the reduction if the factory succeeded in manufacturing below scheduled prices. Until July, 1918, all these national factories were administered by the Supply Department of Aircraft Production. The official control of the factories appears to have been far from complete. It certainly was not sufficiently centralised, and, as a result of this, the factory managements experienced considerable difficulty in obtaining decisions on questions of policy and procedure within a reasonable time. This position accounts to some extent for the administrative irregularities of the managing firms to which attention is drawn below, and for their apparent disregard of Ministry rules and regulations during the earlier stages of the factories' operation. Apparently with the object of obtaining greater efficiency and also for the purpose of establishing a more central authority to which the factory management could refer in all matters of administration, it was decided to divide the headquarters control of them in such a way as to invest the responsibility for allocating orders and the supply of necessary material in the Controller of the Supply Department, and to place the administrative duties connected with output, efficiency, finance, labour, etc., under the control of a new department to be known as the National Aircraft Factories Department. This department was accordingly established in July, 1918, under the control of Mr. Alexander Duckham, who also administered the factories at Oldham for assembling American aircraft. The organisation of the new department and its earlier operations were rendered more than ordinarily difficult by the fact that it was called into existence several months after the factories themselves

[1] (Printed) *Weekly Report*, Section VII, *passim*.

had been established, and also at a critical stage of the war, when the need for aircraft and aircraft parts had become a matter of extreme necessity.

A memorandum issued by the Director-General of Aircraft Production clearly laid down the nature and extent of the relations of the Controller of National Aircraft Factories with other departments of the Ministry.[1] Under the procedure stated in that memorandum, the Controller of the Supply Department had direct control of the production officers at the factory, and dealt with each factory practically in the same way as with an ordinary contractor, but referred in all matters of management to the Controller of National Aircraft Factories. The latter was responsible for the management of the factory, and was the official channel of communication with the Ministry regarding all matters other than those specially delegated to the Supply, Inspection and Technical Departments. He had direct authority to sanction capital expenditure not exceeding £1,000 in any one case. Schemes involving sums in excess of that amount were submitted to the Munitions Works Board. The system of factory accounting and costs was laid down in agreement with the Controller of Factory Audit and Costs, and the Controller of National Aircraft Factories was responsible for seeing that the system was adhered to. The Labour Supply Department of the Ministry of Munitions advised the Controller of National Aircraft Factories regarding all factory labour questions, and factory staff establishments and salaries over £250 per annum were agreed with the Finance Section concerned.

The need for additional output was so great that it became necessary to improvise schemes for hastening the erection and equipment of the new factories. As a result, the principal stipulation made was that a factory should be erected and equipped within a certain time, capable of producing a certain number of aeroplanes weekly. In the cases of Aintree, Croydon and Heaton Chapel, the managing firms were paid part of their remuneration by a percentage on the cost of new buildings and plant, and no detailed drawings, specifications and quantities in respect of the buildings to be erected were in existence when the estimated expenditure was sanctioned, since the clamour for increased output made it impossible to wait for more economical methods. In nearly every instance the original estimate was considerably exceeded. About 97 per cent. of the expenditure on factory construction had been incurred when the National Aircraft Factories Department came into existence. From that time onwards, however, no new expenditure was sanctioned until detailed estimates, specifications, etc., were submitted and considered and the fullest investigation made as to the necessity of the work.

Instructions of a general nature regarding the procedure to be followed in obtaining materials for the National Aircraft Factories were issued by the Deputy-Controller of the Supply Department on 23 March, 1918, and amplified on 28 May following. These instructions laid down, *inter alia*, that except in special or urgent cases all orders

[1] A.S. 25583/1918.

for material exceeding £200 in value should be sanctioned by the Ministry before being placed. There is abundant evidence to show that this regulation was by no means strictly observed, and that some of the factories placed direct purchase orders for very large amounts without reference to headquarters. Subsequently, the necessity for a more detailed system of controlling the increasing purchasing operations of the factories became apparent, and a new procedure was instituted in October, 1918, by which the Ministry was protected against the risk of financial loss owing to over ordering or irregular payments, and against the inequitable distribution of material and competition between buyers for various factories, or the placing of large orders by the managing firms with their own shops.[1] Delay in supply was not infrequent. In many cases this was unavoidable owing to the shortage of certain kinds of material. On the other hand, the factory managements were not always alive to the necessity of anticipating their requirements.

The accounting work in connection with the National Aircraft Factories up to 30 September, 1918, was of exceptional difficulty, mainly owing to the non-observance of Ministry procedure by the factory managers and superintendents and the difficulty of obtaining the prices of stores, materials, machinery, etc., supplied through the Ministry departments. Where the factories were controlled by managing firms, the managements were at first almost entirely unacquainted with Ministry rules and regulations governing expenditure. As a consequence they carried on the financial work of the factories in practically the same way as they had been accustomed to deal with the affairs of their private companies, but on a more lavish scale.

The aeronautical authorities in England strongly recommended the American Government not to assemble their own aeroplanes, but to send the parts to Europe, and to erect assembly factories, preferably in France. It was foreseen that the shipping position would prevent the transport of complete aeroplanes. The advice was not, however, taken at first, and arrangements were made for assembly in America.[2] By October, 1917, the shipping position necessitated the adoption of the plan first proposed and it was decided that Handley Page (O.400) aeroplanes for the American air service should be forwarded in finished parts from the States and assembled in England. A factory site was selected at Oldham. After considering the question of cost, and also the labour position, it was decided to take over Gorse Mill (No. 2), Hollinwood, and the Lilac Mill at Shaw and to adapt them for the work proposed.[3] At that time it was feared there would be a large number of women operatives engaged in the Lancashire cotton works thrown out of employment, owing to the difficulty of obtaining raw material from America, and this consideration influenced the selection of the site. It was also decided to erect and equip additional buildings for assembling and erecting machines, and to provide an acceptance park and aerodrome and a camp for the American staff

[1] N.A.F. 31/7/1. [2] M.C. 329. [3] A.S. 4031/1918.

employed in connection with the work. In January, 1918, a department, known as the American Assembly Department, was established to administer this undertaking. The work of construction began in February, and the Alliance Aeroplane Company (Messrs. Waring and Gillow) were appointed managers of the factory. The company was to provide from their own factories any parts which might be lost at sea. The scale of remuneration was—

(1) £62 10s. per machine.

(2) Ten per cent. on the cost of any parts manufactured in their own factories.

(3) A bonus on economical production, *i.e.*, 20 per cent. on the saving in cost, which was in the first instance to be estimated at £1,000 per machine subject to alteration.[1]

It was arranged that the whole of the capital expenditure as well as the cost of production should be borne by the United States Government. The cost of the factory down to March, 1919, was £1,360,000.

The arrangements provided that the assembling of details into major parts should be carried out by the Ministry of Munitions, while the American *personnel* should assemble the major components into complete machines under the supervision of Air Ministry officials. The output programme arranged was 40 machines a week with spares equivalent to an additional 20 machines.

The progress of construction was slow, owing to the difficulty experienced in obtaining efficient workmen, to frequent labour disputes and to the scarcity of building materials. It was not until early in July, 1918, that the first floor of the Gorse Mill was occupied and operations commenced on the equipment and jigs required for production. The first shipment of parts did not arrive until 20 August, over three months after the date anticipated. The delay was due partly to the failure of the production programme in the States and partly to the fact that certain parts were not forwarded and time was necessary to obtain them in England, where supplies were short. By 13 November, 14 shipments had arrived and about 10 machines were partly assembled. The management of the factory was considered unsatisfactory and a change was contemplated in August, 1918.[2] It was not, however, until December, 1918, that the Oldham factories were taken over by the Ministry.

At its initiation it was hoped by the Supply Department that the American assembly scheme might be used as a means of balancing aeronautical purchases in America with British expenditure on behalf of America in this country.[3] It was, however, finally arranged that the British Government should pay all the costs both of construction and production under the scheme, the American Government making repayment in sterling by monthly instalments beginning in October, 1918.

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[1] A.S. 4031/1918. [2] N.A.F. 11/7/1. [3] M.C. 329.

CHAPTER IV.

SUPPLY OF COMPONENTS AND ACCESSORIES.

I. Introductory.

In pre-war times it was the practice for the contractor to provide all material and accessories required for fulfilling a Government contract for aircraft. As the war progressed, it became increasingly difficult to obtain materials and accessories, and centralised control of certain supplies became necessary. From the beginning of the war the necessity of importing foreign engines made it essential for the Government to assume control of engine supply. It was soon found necessary to increase the production of magnetos, ball-bearings and carburetters, and the method adopted was to place direct contracts for these parts, and to issue them to contractors making engines. Later this policy was extended to piston rings, distributors, sparking plugs, crankshafts and cylinder castings. In June, 1916, the War Department began to organise the production of essential materials, of which there was a shortage, such as alloy steel, fabric and metal fittings.[1] Contractors were still left to make their own arrangements with regard to other materials, applying to the Department only when hastening became necessary. During 1917 these applications became very frequent and it was found that much competition and disorganisation existed in the supply of parts and materials. In July, 1917, all contractors were required to obtain permission and advice from the Controller of Aeronautical Supplies before placing sub-contracts for any material or components used in aeroplane and aero-engine construction.[2] From the information thus obtained the Materials Section was able to watch the output at producers' works and exercise pressure where necessary. In February, 1918, a further step towards centralised control became necessary, and aircraft contractors were instructed to indent directly on the department for materials and accessories, so that the best distribution could be arranged where the department was not supplying direct.[3] The department thus acted as a clearing house and distributed orders in accordance with the capacity of producers.

This control of materials and components made the arrangements connected with contracts, finance and accounting very complicated. In the early part of the war components were sometimes issued without proper records of the transaction being kept, and it was not until 1918 that a satisfactory method of dealing with the situation had been evolved. In the case of material which could only be obtained direct

[1] Hist. Rec./H/1960/2. [2] 87/Contracts/98. [3] A.S. 35898/1918.

from the Supply Department, weekly or monthly requisitions were received from contractors, signed by a local officer familiar with the contractor's requirements. It was not always found possible to ascertain that the contractor accounted satisfactorily for all the material supplied. All technical accessories were held in service stores and issued to contractors on weekly indents by inspectors at the works.[1]

As Government control over various essential materials was extended, the necessity arose for settling some definite procedure for their issue to contractors. There had been a great variety of practice, various articles being treated as free issues in some cases and as chargeable in others, while for other stores no definite prices were fixed. So great were the difficulties experienced in connection with invoicing on account of the absence in formal contracts of terms of issue of materials that investigations into the prices of components were made during 1917 with a view to stating terms and price in contracts, and issue prices were settled in many cases towards the end of 1917.[2] In June, 1918, it was decided that complete engines and hulls for boat seaplanes should be the only articles to be issued free. All other Government property should be issued either for payment in cash or *per contra* debit, and the terms should be inserted in the contract. The components and materials thus supplied for seaplanes and aeroplanes comprised 62 items and for aero-engines 17.[3] It was not until after the Armistice that the method was actually in operation, for the first preliminary and provisional issue of the priced vocabulary for aircraft supplies was not made till July, 1918. Much difficulty was experienced in obtaining issue prices for balloon fabric owing to the variety of authorities responsible for its purchase,[4] and the question was unsettled at the time of the Armistice.

Delay in production was frequently caused by the failure of firms to order materials in time for the department concerned to provide supplies. In order to compel firms to indent on the correct source for their supplies in good time, contractors were notified, on 27 August 1917, that no machines would be accepted unless complete in every particular, except in cases where the items deficient were supplied by the Ministry, and were unobtainable.[5] The shortage of instruments which prevailed during August and September of 1917 caused this policy to have a somewhat adverse effect on output.[6] The failure to order materials in time was, however, often due to the absence of drawings from which quantities had to be calculated, and on the suggestion of the chief production officer, quantity surveys were after November, 1917, issued with the complete drawings showing the amount of material required for manufacture, and this arrangement was of great assistance to contractors.[7]

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[1] A.S. 17544/1917.
[2] A.S. 20610/1917.
[3] A.S. 35898/1918.
[4] A.S. 29507/1917.
[5] (Printed) *Weekly Report*, No. 105, VI. (18 August, 1917.)
[6] *Ibid.* No. 108, VI. (8 September, 1917.)
[7] A.S. 39763/1917.

II. Engine Components.

(a) Carburetters.

As the number of British firms building aero-engines increased it was found that the existing carburetter manufacturers could not cope with demands. Where firms were supplying engines and manufacturing carburetters as well, it was found that engine production suffered considerably. A carburetter section of the Engine Supply Branch was formed in November, 1916, to devote special attention to the problem of accelerating supplies. Early in 1917 there were five firms manufacturing carburetters for aero-engines. Until April, 1917, it was possible to meet requirements, but when the engine programme was increased this was no longer the case. In October, 1917, a production officer was added to the staff of the section. The works of two of the largest firms were extended, but owing to the scarcity of machine tools and labour for building purposes, the extensions were not completed in either case until the spring of 1918, and during the early months of that year there was a serious shortage of carburetters.[1] In April it was obvious that new manufacturing capacity would have to be sought, and gradually many additional firms of cycle and motor accessories makers and brassfounders who possessed suitable equipment were brought in. From this time the output of carburetters steadily increased. The output in April, 1918, was 2,800 a month, and in November, 1918, 11,900.

One of the principal difficulties in extending carburetter production was the claim to patent rights by the parent firms. These firms, fearing the infringement of their patent rights and the loss of royalties, in some cases took serious exception to contracts being placed with other firms without reference to them. As a result the department in some cases lost much valuable assistance, though in others the firm generously gave all possible help in facilitating the manufacture of their carburetters by other firms. Considerable delay in output was also caused by difficulty in arranging prices. Comparison was made between prices for engine carburetters and motor car carburetters. Since the carburetter of an aero-engine had to work at high altitudes and extreme precautions had to be taken against fire, it required higher workmanship and better material and there could be no comparison between the two in regard to price.[2]

(b) Magnetos.

The position of this country in 1914 in regard to the production of magnetos was very grave. Only one firm was producing magnetos and its output for 1913-14 was 1,140 magnetos of a simple type. The Admiralty and War Department endeavoured to meet the early requirements by importation, but by July, 1915, it had become evident that to depend on imported magnetos would hamper the efforts of Britain and the Allies. The Admiralty then undertook to foster the supply

[1] A.S. 14651/1918. [2] Hist. Rec./R/1964/3.

of home-produced magnetos for all the fighting services, and continued this work until it was taken over by the Ministry of Munitions early in 1917. In the summer of 1916 the magneto shortage became acute as the stock of German-built instruments, which had hitherto formed the staple source of supply for the Royal Flying Corps, was rapidly diminishing. Certain American-built magnetos were forthcoming, but in most cases they were completely unreliable as they were intended primarily for automobile service. The British firms engaged on the work were fully experienced in the manufacture of all types of electrical equipment, but repeated failure attended their magneto production for the first 12 months. Towards the autumn of 1916, however, fairly reliable magnetos were being produced at the rate of 20 to 30 per week. The difficulties to be overcome were many. Suitable magnets were not obtainable in the British Isles; nor was the necessary hard rubber insulating material, nor the fine copper enamelled wire, nor oiled silk or paper for insulation. For the best quality enamelled wire it is still necessary to depend to some extent on the United States and for oiled silk on Japanese fabric, but the progress made in providing these four essential materials at home has been wonderful. The shortage of these materials made it impossible to increase the output by repairing damaged magnetos, as the demand for spares could only be met by withholding parts from new production.[1] The technical problems have been solved in a way which does the greatest credit to the manufacturers and the department concerned. Not only has production in quantity been obtained but the quality of the British magneto has reached an extremely high standard.

The ignition plug ranks with the magneto in importance and it presented similar difficulties in production. The pre-war output was insignificant. There were three firms manufacturing and their total output for all purposes during 1914 was not more than 5,000.

(c) Piston and Obturator Rings.

Millions of piston rings were required for the programme of engine production and repair. Many small firms devoted all their energies to producing this piece of metal work, which is particularly intricate because of its delicacy and the exceedingly fine limits required, the frailty of the metal (chiefly cast iron) and the necessity of securing the ring absolutely free from porosity, blow-holes and fracture in order to obtain uniform elasticity in expansion. An innovation introduced for the purpose of securing this uniformity was the internal rolling of the ring by means of a serrated roller, an operation which proved very satisfactory.

Obturator rings were used principally in rotary engines, in addition to the number of piston rings usually employed. Their use was to prevent gas leakage, and they were so constructed and applied as to be forced outwards against the cylinder walls. Much time, ingenuity and money was spent in introducing various designs, improving the silver

[1] A.S. 8838/1917.

alloy from which they were made, and experimenting to prove their efficacy. Opinions differed as to whether the gain in efficiency was worth the large additional cost incurred by their use, for their life was very short, and constant renewals were necessary.

III. Radiators.

It was found in July, 1917, that a shortage of radiators was seriously retarding aircraft production. The difficulty had existed throughout the early part of 1917, but it became acute when as a result of the hostile aeroplane raids the value of large bombing machines became clearly recognised, and special efforts were made to increase the output. All the large bombers had water-cooled engines, requiring radiators of special construction, and in August, 1917, the output of radiators was only about one-fifth of that necessary to meet the new programme. The radiator is part of the engine in the case of aircraft just as it is in the case of a motor-car, but it was foreseen that if radiator design was left to the engine firms, patterns would probably be produced having such excessive head resistance as to impair the performance of the aeroplane. It was therefore decided to make the aircraft firm responsible for the design of the radiator for its own machine, though the actual manufacture was usually carried out by radiator firms. This arrangement would probably have worked very well had proper co-ordination been maintained between the aircraft and engine programmes. Unfortunately, as has been seen, the supply of engines fell into arrears, and it frequently happened that an aircraft firm who had undertaken to supply aeroplanes with a certain engine, had to install engines of another type, and that radiators ordered for the first combination had to be scrapped and another design prepared. The effect of this on radiator production was lamentable. It begat a tendency on the part of the aircraft firm to leave the ordering of radiators to the last moment and it also produced discouragement and distrust in the minds of radiator manufacturers. The difficulty was emphasised by the fact that the number of firms engaged in radiator making was less than a dozen, and that, with two exceptions, they were small-scale businesses. Thus a number of aircraft firms or their agents were bidding against one another for the services of the radiator firms, and were frequently willing to pay a premium to secure the radiators for the lack of which their machines were being held up. The radiator firms in turn paid high wages to their employees, who resisted dilution and opposed anything tending in the direction of quantity production.[1]

It was accordingly proposed that sub-contracts for radiators should be abolished, and that supply should be taken over by the Department of Aeronautical Supplies, so that it might be established on a quantity-production basis, radiators from that time becoming a free issue to aircraft contractors. The first step was to obtain from radiator firms full information as to their existing contracts, their commitments per week and a statement as to their existing output capacity, and the possibility of increasing it. A comparison of

[1] Hist. Rec./H/1960/2.

commitments and capacity showed that in every case firms had undertaken to supply from three to five times as many radiators per week as they were able to produce. It was pointed out to the firms that this constituted a national danger, and a transfer of contracts was insisted upon, so as to reduce the number of types for each firm to a minimum. This process alone resulted in a doubling of output in ten weeks, without any increase either in labour or plant. The factory which offered the greatest possibilities for development was that of the Motor Radiator Manufacturing Company at Greet. The establishment was laid out for the production of tube honey-comb radiators on a fairly large scale and produced 40 to 50 aircraft radiators per week. The plant was entirely self-contained, having a tube mill sufficient to produce all the tube necessary for its output of radiators. The buildings were modern and well lighted, the site was good, and there was ample land available for extension. Moreover, the management was efficient and progressive. On account of its foreign origin, negotiations for the transfer of the business to an English concern were attempted, but broke down at the point where the firm wished to be guaranteed by the department against any possibility of loss, and it was finally decided to take over the factory under the Defence of the Realm Act, and to transform it into a national concern. This was done on 1 January, 1918, and an extension of plant and works arranged. The acquisition of this factory greatly strengthened the department in dealing with radiator contracts and enabled very considerable saving to be effected. The factory was permitted to keep accounts in the same way as a private company and to tender as before against other concerns for radiator contracts. The following incident may be recorded as showing the emergency value of the National Radiator Factory. Early in February, 1918, it was decided to equip the S.E.5 scout machine with an underslung radiator of new design. This type had already been successful in the D.H.9, and as no difficulty was anticipated, and the machine was urgently required in large numbers, some 2,000 radiators were put into production. The first air trials showed that a serious mistake had been made, as the speed of the machines fitted with the underslung radiator was reduced by about 10 miles per hour. A conference of the factory works manager and the S.E.5 designer resulted in the preparation of rough drawings of a new type of radiator, thereby saving the normal period of six weeks usually required for the elaboration of a new design. By working continuously the new radiator was despatched to Farnborough and was tested in the air with the greatest success within forty-eight hours of its conception. In the following week 40 pairs of this radiator were delivered from the National Radiator Factory, the next week 60, the next week 80 and the following weeks 100, so that the anticipated stoppage of production of the machine was altogether avoided. During the last week of March, when the Germans were making their great effort, the S.E.5 played a great part in ground fighting. Over 100 S.E.5 radiators were shot through and in order to replace them a special staff of courier air mechanics was provided. As each new radiator was finished at Greet, an air mechanic set off with it and delivered it to its required destination in France.

In order to secure bulk production it was desirable to standardise radiator blocks. The materials in use were of great diversity and included circular, square, hexagonal and octagonal tubes, as well as brass film of various thicknesses, widths and shapes. Research showed that a radiator tube of 10 mm. diameter and 120 mm. in length gave the best possible results for aircraft, when cooling efficiency and minimum head resistance were jointly considered. This tube represented an improvement of 16 per cent. on the 100 × 7 mm. tube, which appeared to be the best system then in existence. A radiator tube of the new dimensions was ultimately adopted as standard. It was found to be a difficult undertaking to persuade firms to undertake the manufacture of this tubing in sufficient quantities to meet demands, but in the end the cancellation of cartridge contracts made it possible to secure the services of several cartridge firms for radiator-tube manufacture. Considerable time was necessary for the modification of the plant and the production of tools, and in some cases erection of buildings was necessary, but by the middle of June, 1918, complete standardisation had been achieved.

IV. Self-Sealing Tanks.

A shot in the petrol tank is always liable to set fire to a machine. To protect the petrol tank universally used on aircraft from the effects of enemy bullets was the main function of the "Imber" tank. In the case of a hit, part of the rubber cover was automatically drawn into the hole and sealed the tank.

Early in March, 1918, drawings were prepared by the Munitions Inventions Department for an R.E.8 self-sealing petrol tank, to the inventor's design. Owing to the construction of the tank, and the somewhat intricate work involved in the building up of its interior, however, only one firm would undertake the manufacture. The first design specified a sheet of 30-gauge copper sheet and an internal cage of aluminium tubing. After experimenting with tools and jigs for this novel work, Messrs. Ewart & Son, of Letchworth, succeeded in the construction of the first tank. The necessary rubber work was done by another firm. After a further canvass of manufacturers accustomed to sheet-metal work, one or two more were persuaded to undertake production, not only of the R.E.8 type, but also of the tank for the Camel aeroplane. After five months of experimenting, it was found that catalytic action was set up on the surface of the copper shell, owing to its close contact with the rubber, in which was contained a certain percentage of sulphur. The copper sulphide thus produced ruined a large number of tanks which had been made before this was discovered. To overcome this defect the sheet copper was electro-plated. It was soon found that this did not answer the purpose, and 28-gauge tinned sheet steel was substituted. This has since been the standard material for the shell of the "Imber" tank.

From this time production in quantities became possible, and designs of "Imber" tanks for all types of fighting machines were introduced by July, 1918.[1] The drawings for these were quickly

[1] Hist. Rec./R/1960/19.

prepared, mainly owing to the useful spade work done by the manufacturers of the earlier designs, who exhibited great enthusiasm for the work. By the end of October, 1918, "Imber" tanks were being produced for 10 different types of aeroplanes and seaplanes. In June, 1918, the British Engineering Standards Association confirmed a specification for the rubber used in the covering of these tanks, and this was used from that time onward. A certain amount of trouble was experienced in the manufacture of the fittings necessary for these tanks, and it was decided to standardise them as far as possible. In all, some two dozen types of fitting were designed, embodying certain standard dimensions.

V. Ball-Bearings.

Ball-bearings for aircraft and aero-engines, required by the Royal Flying Corps, were obtained through the Transport Department of the War Office, while the Admiralty obtained supplies for the needs of the Royal Naval Air Service. Aircraft ball-bearings, in the early months of the war, were made chiefly by one firm, Messrs. Hoffmann. A certain number required for rotary engines were obtained from France, but as the production of rotary engines was extended it was found necessary to create supplies in England. These were at first principally obtained from the Svenska Kullager Fabriken, of Sweden, through the Skefko Company, their agents in England; and later the manufacture was taken up by the Coventry Auto Machinery Company. The Admiralty made efforts to improve their position by placing large orders in Switzerland, and by arranging for supplies from Messrs. Blackstock. By this means the supply of bearings was just sufficient to meet requirements until the end of 1915.[1]

The demands, both for mechanical transport and aircraft purposes, increased very rapidly; and, at the same time, the supply from the Swedish works became precarious, owing to the numerous cases of losses at sea, and also to difficulties between the English agents and their works in Sweden.[2] At the same time, it was found that the bearings produced by the Auto Machinery Company were unsatisfactory for aircraft purposes. At the instance of the Aircraft Department a conference was convened in July, 1916, at the Ministry of Munitions, at which all users of ball-bearings were asked to state their requirements. As a result, it was found that the situation was rapidly becoming more serious, and that the supply was likely to be only half the requirements. The Ministry immediately took steps to carry through extensions to the works of Messrs. Hoffmann and Messrs. Ransome, while the Skefko Company was persuaded to undertake the manufacture of the balls in England, instead of depending on supplies from Sweden.[3] The Naval Air Service also financed extensions at Messrs. Blackstock's works, and enquiries were made as to the supply available in the United States. The balls for aero-engine work had to be of the highest class, owing to the severe wear to which

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[1] 87/Contracts/35. [2] M.A./B/19. [3] 87/Contracts/35.

they were subjected, and, with the exception of those supplied by the Skefko Company, balls of foreign origin were not considered sufficiently reliable. It was urged by the authorities responsible for aero-engines that priority of all bearings made by the high-class English makers, Messrs. Hoffmann, should be reserved for aviation purposes, and in January, 1917, Messrs. Hoffmann were instructed to give preference to aircraft orders.[1] At the same time a large order was placed in America,[2] and the Department of Aeronautical Supplies took over complete control of ball and roller bearings for aeronautical work. Contractors had to notify their weekly requirements and those of their sub-contractors, and the demands were checked by the production officers to prevent hoarding.[3] Owing to delays in getting into full production, these steps were hardly adequate to meet the programme arranged at the end of 1916, and the ball-bearings position caused grave anxiety throughout the first six months of 1917. Considerable reliance was still placed on importations from Sweden, and heavy losses were experienced during the spring of 1917. Arrangements were made with the Admiralty for a variation of route and better protection for carrying vessels[4]; but constant losses made some insurance necessary, and orders covering all shipments expected from Sweden were placed in America.[5] To secure safe delivery the bearings were, in some cases, transported in warships, their bulk and weight being small.[6]

The increase in the air programme in the summer of 1917 completely altered the situation. Supplies which had barely sufficed for the smaller programme, were wholly inadequate for the new one, in which the requirement was trebled by the spring of 1918. Other firms were drawn into the industry and further extensions were made to existing works,[7] but engine production was seriously delayed on account of the inadequate supplies of ball-bearings, the delay in output of Rolls-Royce engines being specially serious, and occurring in spite of the fact that Messrs. Hoffmann concentrated on these bearings to the exclusion of those for other engines.

During 1918 allocations of ball-bearings were made by the Ball-Bearings Branch of the Ministry. The requirements of the various departments were ascertained and a proportionate percentage of the total available supplies was allotted to each department. The efforts of the Ministry to increase supplies took effect early in 1918 and the shortage was thus overcome.[8]

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[1] Vol. VIII, Part III, p. 76.
[2] (Printed) *Weekly Report*, 89, IV. (28 April, 1917.)
[3] A.S. 7236/1917.
[4] (Printed) *Weekly Report*, 88, IV. (21 April, 1917.)
[5] *Ibid.* 90, IV. (5 May, 1917.)
[6] Hist. Rec./R/1960/3.
[7] D.M.R.S. 467 D.
[8] Vol. VIII, Part III, p. 77.

VI. Airscrews.

In 1914-15 there were only five airscrew manufacturers, but at the end of 1918, 68 contractors were busily engaged on this work. Furniture makers, building contractors and pattern makers were represented among the firms employed. Owing to the exigencies of war and the necessity for economising timber, various methods of airscrew construction have been introduced, of such a nature that continuous lengths of wood for lamination can be replaced by two or more pieces, resulting in the using up of many short ends of material which would otherwise be scrapped. The methods adopted are known as the Oddy construction and Cleaver construction.

No great advance has been made in the machinery employed in the construction of propellers, as it has been found from experience that in the hands of a capable workman, a laminated airscrew block can be roughed down and finished with almost the same speed as with a machine. Special arrangements have always been found necessary for testing aircraft propellers. Airscrew testing plant was in existence prior to the war at Farnborough, and until 1918 the Farnborough plant was capable of dealing with all requirements. By that time the progressive increase in output of airscrews outgrew the facilities at Farnborough. The Aeronautical Inspection Department accordingly put in hand an airscrew test-house at Milton. This plant was brought into use in the summer of 1918 and had the advantage over the Farnborough installation of being sufficiently powerful to subject to spinning test the largest airscrews then made.

In the early days of the war many airscrews were finished either by French polishing or by the use of inferior varnishes that failed to protect adequately the woodwork of the airscrew against the changing atmospheric conditions encountered during use. To overcome these difficulties, finishing schemes were drawn up, and all airscrews were finished with tested and approved products, from wood-fillers and under-coatings up to the finishing varnish itself. To ensure that these tested materials were correctly and uniformly applied by all users, manufacturers of the materials comprised in such finishing schemes were required to publish detailed directions for their proper application. These directions were tested and approved by the department before issue.

VII. Aeronautical General Supplies (A.G.S. Parts).

A.G.S. parts are the small machined parts of an aeroplane, including nuts, bolts, turnbuckles, split pins, etc. They are used in such large quantities that at an early date it was found advisable to buy them in bulk and re-issue them to the trade. The deliveries from direct contracts were made to central stores and despatched from these stores to aircraft builders and the Services by issue warrant on receipt of indents. By this system it was possible to create a reserve for any emergency. The supply was, however, never completely controlled, but in 1917 difficulty in obtaining supplies tended to make aircraft contractors more and more dependent on the department for placing their orders.

Though A.G.S. parts are articles of a high-precision character, it was found that the most successful contractors were those who had not made bolts, nuts, etc., before, and a great variety of trades was represented among A.G.S. contractors. Gold and silver smiths, cycle, typewriter, gramophone and sewing machine manufacturers were all employed.[1] As far as possible, the firms were organised so that certain manufacturers undertook certain sizes of bolts, nuts, etc. Since, however, there was no centralised control of all work of this type, the efforts of the aeronautical authorities were not very successful, since Admiralty and Merchant Service orders were placed promiscuously with the same firms. It was soon found that, partly owing to this confusion of orders, there was not sufficient automatic machinery in the country to produce the parts required. Many of the firms engaged in this manufacture had taken it up purely as a war measure and could not be expected to go to the expense of buying automatic machinery at inflated prices for the purpose of manufacturing aircraft parts for the duration of the war. To meet this difficulty an estimate was made of the amount of machinery required to manufacture the A.G.S. parts programme from June, 1917, to June, 1918, and a proposition was put before the various contractors to install the necessary machinery on a hire-purchase system, with the option of completing the purchase at the end of the war.[2] Arrangements were made to manufacture and import the machinery required from the United States. The housing of this machinery necessitated large extensions to various firms and considerable assistance was given to them in this connection. The production of one large firm of sewing machine makers was increased from 1¾ million parts per month in April, 1917, to 2½ million in September, and finally to 5 million.[3]

Contracts were also placed in the United States. Generally speaking, these contracts were most unsatisfactory, as with very few exceptions, the American firms never even approximately met their promised deliveries.

In October, 1917, the supply of these parts was the cause of anxiety, and it was found necessary to exercise some control over supply. Firms, instead of placing contracts wherever they pleased, had to send in estimates of their requirements to the Supply Department and supplies were allocated to them from suitable sources.[4] Extreme difficulty was experienced in finding contractors for nuts and bolts, and in November the assistance of the Department of Area Organisation was sought and large orders for A.G.S. parts were placed for the Department of Aircraft Production through the local Boards of Management under the Ministry scheme of Area Organisation. The Dublin National Fuse Factory and the Derby National Shell Factory were both used for the production of these parts, and it was hoped that the information obtained as to the true cost would be of great value to the Ministry in assisting the reduction of prices.[5]

[1] M.C. 340.
[2] (Printed) *Weekly Report*, No. 108, VI. (8 September, 1917.)
[3] Hist. Rec./R/1960/5.
[4] A.S. 30635/1917 ; 31460/1917.
[5] M.C. 601.

A comparison of monthly ouput is given below:—

	June, 1917.	*November*, 1918.
Turnbuckles	36,000	1,162,000
Bolts	1,860,000	10,500,000
Nuts	2,630,000	13,600,000
Pins	548,000	2,900,000

VIII. Aluminium and Copper Tubes.

Large supplies of aluminium were required for aircraft work, chiefly in the form of aluminium tubing. Each aeroplane is provided with an air-speed indicator, from which two lengths of aluminium tubing are led to a convenient point, usually on one of the outer struts, where they terminate in the form of pitot tubes. In October, 1917, the demand for tubing for this purpose had reached 36 miles per month. It had outstripped the possible production in aluminium and a certain quantity of it had to be provided in copper. This was objectionable for two reasons; it increased the weight and it interfered with the supplies of copper tube for other purposes. In October, 1918, the demand had increased to 120 miles per month for pitot tubing, together with 140 miles for self-sealing tanks. Nevertheless, it was possible to obtain all this in aluminium owing to the fact that the extrusion process had been introduced to supplant the ordinary tube-drawing method. This had also produced a notable saving, the price falling from 11s. 6d. per lb. for draw-bench tubing to 5s. per lb. for extruded tubing.

The chief difficulty in obtaining supplies of copper tube, during the first two years of war, was caused by the entire lack of standardisation. The aircraft firms working for the War Department ordered tubes by specifying the external diameter with the thickness expressed in standard wire gauge. Firms working for the Admiralty, on the other hand, ordered copper tubes by specifying the internal diameter or bore, and the thickness expressed in Whitworth's decimal gauge. Firms working on French engines, and those requiring copper tube for export to France, specified by means of metric sizes, in which the internal and external sizes were given, and the thickness found by subtraction. It was found at the beginning of 1917 that there were more than 650 different sizes of copper tube on order. This would have necessitated a similar number of different dies and mandrels, multiplied by the number of draws necessary to get down to the required size. It was, of course, impossible to fulfil all these orders, and manufacturers had contented themselves with picking out the easy sizes, or those for which they received very large orders. All orders for copper tube received during the first two years of the war, which did not happen to come within these categories, were entered in books by the manufacturers, and left there.

All these difficulties were overcome at the beginning of 1917 by (1) standardising one gauge in 25 sizes,[1] (2) arranging for stocks of the standard sizes to be available for immediate delivery, and (3) prohibiting the use of non-standard sizes.

[1] A.S. 2509/17.

IX. Steel Tubes and Axles.

At the time of the amalgamation of the Admiralty and War Department supply branches in March, 1917, it was found that 90 per cent. of the aeroplane steel tubing used on army machines came from one firm only. This firm also supplied 15 per cent. of the tubing used on naval machines, the remaining 85 per cent. being obtained from five other firms. The Admiralty thus controlled most of the tube makers, and the greater part of their output was required for naval purposes.[1] A policy of broadening the basis of supply had immediately to be adopted. Other firms were instructed in the manufacture of tubing and at the time of the Armistice 17 firms were contributing to the total output. Aircraft tubing requires special treatment which was unknown to the tubing firms until they were instructed by the production and inspection officers attached to the department. It became possible not only to improve the quality of the tubing but to utilise a cheaper and more plentiful form of raw material. During 1917 some difficulty was experienced owing to the interruption of supplies of raw materials (steel hollows) from Sweden and action was taken to utilise only American hollows.[2] The standardisation of tubing and the preparation in August of schedules of tubing required for each type of machine[3] enabled prices to be fixed and very much facilitated the work of supply. The principle of making one firm responsible as far as possible for certain sizes was adopted, as in the case of other standardised materials, and resulted in the production of larger quantities with the same plant. From the experience of thin steel tubing obtained in connection with the supply of aircraft tubing a new principle has been evolved which is now being applied to the construction of complete aeroplanes in high tensile steel.

X. Cable Wire Rope.

Before September, 1917, there was little control over the supply of wire rope, with the exception that main contractors' orders were approved by the Department of Aeronautical Supplies before being passed to a supplying firm. In September it was decided to control production and on 1 October large contracts were placed both for standard and non-standard specifications. The supplies of wire rope were sent direct from the makers to the consumers, a certain quantity always being kept in store for emergencies. All wire rope production facilities were controlled by the Assistant Controller of Materials and Priority (Admiralty). This policy was the means of standardising prices.

The monthly production of wire rope for aircraft purposes in September, 1917, was 1,918,000 ft. In January, 1918, production had risen to 4,353,000 ft. and at the date of the Armistice to approximately 5,600,000 ft. per month.

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[1] C.R. 4447.
[2] (Printed) *Weekly Report*, No. 120, VIII A. (1 December, 1917.)
[3] *Ibid.* 107, VI (1 September, 1917); 105, VI (18 August, 1917).

XI. Aircraft Instruments.

Until the formation of the Aeronautical Supplies Department, the instruments required by the Royal Flying Corps were obtained by the Supply Department of the Directorate of Military Aeronautics, tested and stored at the Royal Aircraft Factory and issued from there as required by contractors or the service.[1] The Royal Naval Air Service provided and tested its own instruments. At the beginning of 1916 there was a shortage of instruments, since in many cases those provided before the war were found unsuitable for the changed conditions of 1916. Compasses especially were short, as a suitable type had only just been developed. Few firms were able to make them, and others had to be trained for the work.[2]

When the Department of Aeronautical Supplies became responsible for the production of instruments for both Services, the stores at Farnborough passed under the control of the Royal Flying Corps. Instruments for the Corps were still tested at the factory before delivery into store, but no provision was made for the inspection of the small number of instruments required by the Royal Naval Air Service and these instruments were stored in a different place. For instruments required by contractors the Aeronautical Inspection Department had to indent on the Service stores. Thus instruments were delivered from the contractors of the Supply Department to the Service stores and then re-issued to other contractors. The supply branch had no check on such issues and owing to the irregularity of reports made from the stores, never had a picture of the exact situation.

The need for a central store under the control of the Supply department was obvious, and in August, 1917, an Aeronautical Stores section was set up as part of the Central Stores Branch of the Ministry, and was placed in control of the instrument store at the Royal Aircraft Factory as well as the stores at Sheffield, Birmingham and Regent's Park.[3] From this time allocation to the Services and contractors was arranged by the Instrument Section of the Supply Department, requisitions being received from the Services in the ordinary way and authorised demands being forwarded by the contractors. Requisitions for special instruments and accessories were also received from the Armament Section of the Technical Department.

The Instrument Section was responsible for (1) provision of standard instruments, such as altimeters, airspeed indicators with pressure heads and pitot tubing, revolution indicators with gear boxes and flexible drives, air and oil pressure gauges, dashboard lighting sets, radiator thermometers, clinometers and watches; (2) allocation of standard instruments to contractors and the Services; and (3) supply of special instruments and certain accessories, such as safety belts and life

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[1] M.A./P/58.
[2] M.A./Miscell./2246. In August, 1918, the Admiralty became solely responsible for the supply of aero-compasses. (C.R.V./Gen./2540.)
[3] A.S. 23013/1917.

belts, speaking tubes, bombsights, navigation instruments exclusive of compasses, fire extinguishers, kite balloon instruments and testing instruments.

The operations of the Ministry regarding the manufacture of instruments had the effect of opening up a new industry in Great Britain.[1] The production of standard instruments to keep pace with the increasing demands throughout 1917 became a most difficult matter because only a small number of firms were capable of doing the high-grade precision work required. The shortage of skilled labour and the general dilution were serious obstacles in work of this nature, and though a great deal of experimental work was required, the available firms were unable to spare skilled men to carry it out. The demand for experimental work was problematical and did not encourage outlay, and excess profits duty operated to discourage it. A further difficulty was the poor and variable quality of the material available. Thus circumstances made it advisable to concentrate research work as far as possible at the National Physical Laboratory and Royal Aircraft Factory, and leave the manufacturers to meet the demand for standard instruments.[2] The anticipated demands for September, 1917, were 1,800 sets, increasing to a monthly requirement of 2,500 in February, 1918.[3] The monthly output aimed at in June, 1916, had been only 800 sets.[4] It was necessary to assist manufacturers to increase their output by obtaining authority for the erection of additional buildings and plant, by supplying them with pressings, movements and other components, and above all by protecting them from the recruiting sergeant. Many of the firms employed were quite new to the work and had to rely very largely on the assistance and instructions given by the Royal Aircraft Factory.

The position with regard to some types of instrument was particularly difficult, and assistance was sought from Switzerland. A supply of watches at very reasonable prices was assured by placing direct contracts with Swiss manufacturers, and a large contract for aneroids was placed with the Zenith Company.[5] The supply of air-speed indicators was originally derived from only three manufacturers, and as their combined efforts were not sufficient to produce the necessary quantities, some of the components were ordered in Switzerland. New contractors were supplied with these and other parts and instructed as to their assembling and calibrating.[6] This course not only assured a constantly increasing supply, but enabled the department to obtain the instruments at a considerably lower price, in spite of the increase in the cost of labour and material. The supply of pressure gauges of various types presented perhaps more difficulty than any other instrument. English gauge-makers had never been organised for large production, and, moreover, they had relied largely upon France and Germany for the component parts, mechanisms, Bourdon tubes, etc. The difficulties were almost entirely overcome

[1] For a detailed account of the action taken see Vol. XI, Part III.

[2] A.S. 26623/1917.

[3] A.S. 26938/1917.

[4] M.A./Miscell./2246.

[5] A.S. 22074/1917.

[6] (Printed) *Weekly Report*, No. 120, VIII A. (1 December, 1917.)

by placing contracts in Switzerland for small mechanisms, 40,000 of which were ordered on most advantageous terms, and by encouraging firms to undertake the manufacture of Bourdon tubes. A well-known firm of gold refiners rendered valuable assistance, and subsequently produced tubing equal in quality to any obtained previously from abroad. The following figures show the increase in the number of sets of instruments delivered :—

Date.	*Approximate Monthly Deliveries.*
January, 1916	300 sets.
January, 1917	800 ,,
July, 1917	1,000 ,,
July, 1918	6,000 ,,

Special instruments were required at the testing stations, and much of the work done by the Instrument Section, which had been formed in the Technical Department early in 1917, lay in the direction of improving the equipment of the stations and co-ordinating the methods of test of the Royal Naval Air Service and Royal Flying Corps. In the reorganisation brought about by the formation of the Air Ministry, the Instrument Section was transferred to the Armament Branch, and a great deal of work was done in the direction of standardising the electrical equipment of the two Services, in order to facilitate manufacture.

XII. Armament, Flares and Fireworks.

Q.F. guns and machine guns for aircraft were at first requisitioned as part of the Army and Naval requirements, and issued to the Air Services. Soon after the formation of the Air Ministry it was decided that it should deal direct with the Ministry of Munitions in all matters relating to such stores as were used by the Air Force only, *i.e.*, heavy guns—Davis, Q.F. Crayford, C.O.W. Mark III, S.A. Mark V and Vickers Automatic Mark III, and Vickers and Lewis guns accessories and certain flares and fireworks. In July, 1918, it was arranged that the Air Ministry should also deal direct with the Ministry of Munitions as to the supply of all air pattern machine guns and stores and ammunition required for their use, whether for the Royal Air Force or for the Allies. The War Office continued to deal direct with the Ministry as to the supply of all ground pattern machine guns, whether for use in the Army or Royal Air Force.[1] The design and development of armament with its accessories and fittings was carried out by the Services.

Provision for the supply of flares and fireworks was made by the Trench Warfare Supply Department from the summer of 1916. An account of the composition of these flares and the arrangements for their supply will be found elsewhere.[2]

[1] D.M.R.S. 467.

[2] Vol. XI, Part II, Chap. VII.

XIII. Armament Fittings.

Towards the end of 1916 a small section was formed under the Directorate of Aircraft Equipment for dealing with accessories, including gun mountings, gun sights, bomb carriers, bomb ribs, interrupter gears, and a few miscellaneous articles. When this section was transferred to the Department of Aeronautical Supplies it took over in addition the supply of aeroplane wheels and tyres, and in May, 1917, it also became responsible for packing cases, armament fittings and accessories for the Royal Naval Air Service. In December, 1917, the supply of castor oil, and in January, 1918, electrical accessories (except those for engine ignition) were transferred to this section.

Up to May, 1917, it was the practice for the section to make its own estimate of requirements. This proved unsatisfactory, and it was decided to base manufacture upon requisitions received from the Services. These requisitions, however, were almost invariably for such small quantities that manufacture on a production basis was impossible. During the summer of 1917 production was assisted by the formation of a Provision Branch, whose duty it was to requisition armament accessories and to see that proper drawings and specifications were to hand. It was not until the end of October, 1918, that it was possible to obtain a programme for a six months' supply of some of the principal articles dealt with, and even at this date the programme was not complete.

When the war started, the armament of aeroplanes was rudimentary, and orders were in most cases merely for experimental stores until 1916, when more or less standardised gear had been evolved. Larger orders were then placed, but all forms of accessories were undergoing constant modification and improvement throughout the war, and production was greatly delayed on this account. The Constantinesco gun interrupter gear especially was the subject of many modifications, no less than 147 being received during the first six weeks after the order for the first batch had been placed.

The dependence of Great Britain upon Germany for supplies of optical glass before the war had an adverse effect on the supply of such instruments as required lenses in their manufacture. Aldis gun sights involved in the case of each instrument two at least of the the most difficult types of optical glass. British firms manufacturing this glass were liable, even at the end of 1917, to have failure of melts. The shortage of sights was so serious in September, 1917, when production had reached only 400 per month, half the estimated requirements, that French aid was invoked in spite of the uncertain quality of their products. The situation was still grave at the beginning of 1918, and it was suggested that the French should be pressed to provide raw glass instead of lenses, their productions being very inferior to those of British manufacturers. By March, however, sufficient supplies were becoming available from home sources.[1]

[1] D.M.R.S. 467 G; C.R.V./Gen./1814.

CHAPTER V.

CONTROL OF MATERIALS.

Some account has been given in Chapter IV of the gradual assumption of control of various materials and components by the Government Departments concerned, and the effect of this upon the supply organisation. One of the principal reasons for the extension of control over materials was the necessity for assuring supplies of uniform and suitable products.

The lack of uniformity in the results obtained from different brands of dope, and the harmful effects of some of the dopes upon employees using them brought the dope question into prominence at an early date. In May, 1916, the Inspection Department established a Chemical Section to examine all the ingredients employed by dope manufacturers and to ensure the provision of uniform and dependable dope. Chemical laboratories were established in space placed at the disposal of the department by the Governing Body of University College, Gower Street. Great difficulty was found in providing an adequately trained staff, since chemists were in great demand for the manufacture of explosives, etc., and the stocks of German chemical apparatus, upon which chemists in this country practically depended before the war, were nearly exhausted, while British manufacturers were not yet in a position to provide very efficient substitutes. The work in the laboratories was soon extended to the examination of lubricating oils, petrol, petrol-resisting hose, rubber shock absorber cord, glue and plywood. In addition to testing all the non-metallic materials employed in British aircraft construction, the headquarters organisation was required in 1917 to undertake the examination of enemy war material captured in the field. The Aeronautical Inspection Department's laboratories were very well equipped for these purposes.

I. Steel for Aircraft.

(*a*) Carbon and Alloy Steels.

At an early period in the war, difficulties were experienced by the War Department in obtaining supplies of aircraft steel. This was not due so much to actual shortage as to the difficulty in getting comparatively small quantities put through the cogging, rolling and heat-treatment processes. The makers found it easier to deal with the larger quantities of metal required in the larger sizes used for shell making, and it was only by constant pressure that the War Department could get sufficient material treated to meet aircraft demands.[1]

[1] C.R. 4447.

A section of the Directorate of Military Aeronautics was set up in October, 1915, to trace and hasten the orders placed by contractors, and to give technical assistance as to steel. In order to decentralise the growing volume of work, outside stations were established at Sheffield and Birmingham at the end of 1916. The Admiralty also had officers at Sheffield responsible for supplies for the Royal Naval Air Service, and a great deal of competition arose between the two offices, as supplies of steel became more and more difficult to obtain. Early in the war there had been no restriction on main contractors' obtaining supplies of raw material where they pleased. The result was that many small orders were placed with various firms, and production was handicapped accordingly. Several of the large contractors placed orders through agents, and this procedure caused much confusion as to ruling prices, as agents were very reluctant to disclose their business transactions. The bulk of the raw material was purchased in South Wales, Scotland and Teeside, on account of the lower prices ruling there, and was sent to Sheffield for rolling and heat treatment, thus causing much congestion of railway transport.

In July, 1916, control over the sale of certain classes of steel was assumed by the Ministry of Munitions, and in November complete control over manufacture was established.[1] A bulk allocation was granted by the Ministry to the War Department for aeronautical work, and these supplies were allocated by the Department to their contractors for steel and metal parts.[2]

The department was at liberty to obtain steel wherever it desired as long as the allocation was not exceeded. In September, 1917, a new procedure was instituted which included the control of steel of all descriptions for aircraft work. Aircraft contractors had to place their orders with the department, and requirements were placed from time to time before a sub-committee of steel manufacturers, who arranged for the manufacture by firms capable of doing the work.[3] The only exception to this arrangement was high speed or crucible carbon steel. The quantities dealt with were so small that the former practice, whereby individual consumers were allowed to order their supplies from the manufacturer to whose steel they were accustomed, was still continued, except in the case of some large firms and the national factories, which were more conveniently supplied through the Department of Aeronautical Supplies.[4]

A central control depôt was established at Sheffield, the centre of the alloy steel trade, and by placing direct contracts it was possible to restrict each steel maker to limited sizes and specifications. Alloy steel was at this time a limiting factor in engine production and great pressure was brought to bear on steel makers to increase their output. The estimated requirement was very heavy, rising to 4,000 tons per month in December, and 6,000 tons per month in July, 1918.[5] The

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[1] *Steel Supplies Orders*, 7 July, 1916; 20 November, 1916.
[2] 87 Contracts/98.
[3] (Printed) *Weekly Report*, No. 103, VI. (4 August, 1917.)
[4] A.S. 27975/1917.
[5] Hist. Rec./R/1960/8.

production was in September only about 1,300 tons per month. Many steel makers were allowed to install electric furnaces and heat-treatment plant, and by this means their output was greatly increased. The control of orders also tended to aid production by making possible running contracts with steel makers. Main contractors passed their orders through the Sheffield office and supply was arranged from stock or off running contracts. In April, 1918, the schedule of stampings for Dragonfly engines was issued to the Sheffield office with an exact statement of the weight and section of steel required by stampers for the manufacture of 1,000 engines and parts. This was a great advance on anything previously achieved and amounted to a saving of possibly two months in placing steel orders.[1] By July, 1918, output of alloy steel had been increased to 6,600 tons per month, but a change in the engine programme made such a large production unnecessary, and the output was again reduced to about 3,000 tons per month.

Though the method of production was sound and secured output in bulk, it had certain disadvantages, particularly in relation to the drop-forging industry. The heat treatment required differed for the different classes of casting, and information regarding the treatment had to be passed on to the drop forger who used the steel. In dealing with such a large quantity of small parcels errors were apt to occur, with the result that forgings did not always receive the correct heat treatment and were sometimes spoilt. In addition, the drop forgers were sometimes supplied with a brand of steel for the heat treatment of which their plant was not suited.[2] This was such a serious problem that the question of modified control, as in the case of high-speed steel, was being considered, by which within certain limitations drop forgers should be allowed to obtain steel direct from the manufacturers if they desired.

Before supplies were controlled, great difficulty had been experienced on account of the variation in price. Contractors naturally wished to obtain their supplies at the lowest rates, and this had led to overwork at certain steel firms. When the new procedure came into effect a general average was taken of the purchase price of each specification, certain overhead charges were added, and a fixed price thus obtained.

(*b*) AERO-ENGINE STAMPINGS, FORGINGS AND CRANKSHAFTS.

In the first few months of the war the production of aero-engines was so small that the question of obtaining drop forgings and stampings for engine manufacture was not a serious one, and was left entirely to the aero-engine contractors. By the summer of 1915 it became apparent that contractors were meeting with increasing difficulties in obtaining stampings, and this difficulty was put forward with increasing frequency as an excuse for failure to deliver engines at the specified date. Large firms, owing to their wealth and influence, suffered less in this respect than small firms, so that, in addition to

[1] (Printed) *Weekly Report*, No. 139, VII. (27 April, 1918.)
[2] A.S. 22891/1917.

the supply of forgings and stampings being inadequate, it was unevenly distributed. About the middle of 1915 a committee was formed of the stampers employed by the contractors for Army aircraft, with a view to considering how the work could be expedited.[1]

The increasing demands for stampings for all departments led to the formation of a small section of the Materials Supply Branch in November, 1916, to deal with stampings, and also with sheet-metal pressings for aeroplane construction. No attempt was made to control the stamping industry or to ration supplies evenly among engine contractors. No steps were taken to put down new plant, though the heat treatment and testing facilities for dealing with aircraft steels were utterly inadequate. The system of hastening adopted by the section was only effective for a very short time. With a rapidly increasing demand for stampings, an increasing proportion of the orders fell into arrears, and in the end practically every order was being hastened, the net result being the same as if none had been.

The Aero-Engine Section (Forgings) had realised the necessity for a far more vigorous campaign than that of mere hastening, and a big plan for extending the stamping shop and the erection of a machine shop under a State subsidy had been embarked upon at the works of Messrs. Ambrose Shardlow & Company, Ltd., Sheffield. The work on this extension had started, when in February, 1917, the plan was somewhat curtailed by the Controller of Petrol Engines, who decided to install a large machine shop at Messrs. Daimler's, Coventry. This National Crankshaft Factory, as it was called, was to have a capacity of finishing from the roughed state 150 six-throw and 150 four-throw shafts per week. In April, 1917, it became apparent that the extension at Messrs. Shardlow's for crankshaft stampings, even when fully operative, would be insufficient. It was also apparent that facilities for stampings other than crankshafts were hopelessly inadequate, especially in the case of the heavier stampings requiring a three to four-ton drop hammer. A large extension to the River Don works of Messrs. Vickers, Ltd., was accordingly put forward in April and sanctioned. This extension was to cater for the production of stampings only. At the same time, the Admiralty had embarked on an extension to the plant of Messrs. Thomas Firth, Sheffield, for the production of four-throw crankshafts as plain hammer forgings, to be gapped and rough machined in a special machine shop to be erected for the purpose. Other extensions had been arranged by the Ministry of Munitions at Messrs. Thomas Smith's Stamping Works, Coventry, at the Scottish Stamping Works, Ayr, and at Messrs. George Turton Platts, Sheffield.

As labour and materials for building were difficult to obtain, very great delays occurred in the fruition of these schemes. Messrs. Thomas Smith, of Coventry, were the first firm in operation. Although valuable assistance was given, the efficiency of the plant was low, because the advice of the Ministry of Munitions in regard to the erection of steam hammers in place of drop hammers had not been followed. Messrs. Vickers were next in operation and their new shop resulted in a small

[1] HIST. REC./R/244/1.

output in March, 1918. Full production was not reached, however, until October, 1918—exactly one year behind scheduled time. Messrs. Shardlow produced their first six-throw shaft as a die forging in June, 1918, but owing to breakage of dies, etc., they did not produce any quantity until September, 1918, and had not reached full production at the time of the Armistice. The Scottish Stamping Company's venture proved a failure. As a small private business, undertaking small stampings and hand forgings, it had been fairly successful, but a great error in judgment was made in insisting on a very large extension for heavy stampings requiring three to four-ton hammers. The sub-stratum of the plant was found to be loose sand and the capital expenditure involved in re-bedding all the hammers in solid masses of concrete practically crippled the firm and made competitive prices impossible. The Admiralty scheme at Messrs. Firth's was so long in maturing that it was eventually abandoned.

When it was realised in June, 1917, that the extensions at Messrs. Vickers would not produce their full results for many months, two large contracts were placed in America for crankshaft stampings for the R.A.F.4, B.H.P., Arab, and 200 h.p. Hispano-Suiza engines. Delay occurred in furnishing prints and contract matter, but, in spite of this, the importations helped to relieve the situation. The quality of the steel, however, was not so good, nor the inspection so rigorous, as in this country.

Owing to the large orders that had been placed for aero-engines with French firms, the raw material for which had to be furnished from England, the demand for Hispano-Suiza crankshafts became the most serious item of all. In June, 1917, the production of these was approximately 60 per week, whereas the demand was 250. To meet this condition contracts were placed on a large number of firms who had never produced an aero-engine crankshaft, and though the difficulties encountered were very great, and prices and rejections and defects were high, by September, 1917, the output of crankshafts for French Hispano-Suiza engines had risen to the desired figure of 250 per week. In October, 1917, supplies from America began to arrive,[1] and the position was much more satisfactory.

In open competition with other Government Supply Departments aeronautical work was at a disadvantage, owing to the much greater difficulty in manufacturing stampings to such fine limits and in such high-grade steel. The Assistant-Controller of Forgings and Castings, Ministry of Munitions, was therefore approached in July, 1917, with a view to obtaining unified control.[2] It was arranged that all contractors' requirements should be submitted to the supply departments, who placed them before a committee consisting of properly elected representatives of the trade, the Assistant-Controller of Forgings and Castings and representatives of each supply department concerned, presided over by a member of the trade. The committee

[1] (Printed) *Weekly Report*, No. 115, VI. (27 October, 1917.)
[2] A.S. 22891/1917.

allocated each order in accordance with the capacity of the stampers, the order thereafter being regarded as a private one between the contractor and the stamping firm. In May, 1918, however, a far more vigorous policy was embarked upon. The development of the industry on the lines of economic pooling of die-sinking facilities and extension of works was pressed by the Ministry, and aircraft work was facilitated by these means. In spite of a drop in total output of stampings, the efforts of the Department of Aircraft Production resulted in a steady rise in output of aero-stampings.

The possibilities of drop stamping were exploited very considerably by aero-engine work during the war, two striking examples being the production between dies of the crankshaft for the 100 h.p. Monosoupape engine, and the six-throw crankshaft for the R.A.F. 4a. engine. The former was originally produced as a hammer forged solid cheese, but eventually a very efficient stamping in two halves was produced by Vickers and Turton Platts, thus considerably reducing the amount of machining required. The R.A.F. 4a. crankshaft was a particularly difficult crankshaft to make by any process. A method of stamping was ultimately devised, based on an American principle.

Throughout the whole period of the war great difficulties were experienced by reason of the poor quality of alloy steel supplied to the forgings firms. In 1916 and the early part of 1917 it was estimated that the rejections of finished crankshafts for hair cracks in steel varied between 50 and 90 per cent., and for a long time 80 per cent. was quite a common figure. The same trouble arose, to a slightly less extent, with forgings other than crankshafts, and the rejections for cracks were always a serious feature. As a result of experiment it was found that much of the trouble could be eliminated by the surface machining of ingots or billets at an early stage of manufacture by the steel-makers. This eliminated surface defects, and reduced the chance of small surface cracks being aggravated by heat treatment and temperature changes. As a result the rejection of crankshaft material eventually fell to 10 to 15 per cent. Continued complaints were, however, made by the smaller stamping firms of the quality of the steel supplied to them. Though it is recognised that strong grounds existed for these complaints—since it was impossible to arrange for every steel-maker to machine billets in the manner described—it is probable that a large proportion of the trouble was due to a certain lack of co-operation between the master stampers and the steel-makers.[1]

(c) Aeroplane Pressings and Stampings.

Until September, 1917, the only aeroplane pressings and stampings supplied by the Department of Aeronautical Supplies were those for the F.E.2B., F.E.8 and S.E.5 aeroplanes. In September, 1917, the department undertook the provision of the bulk supply of complete press work fittings and machine drop forgings required for the Handley Page programme.[2] This involved heavy responsibility, as the fittings

[1] Hist. Rec./H/1960/2.
[2] (Printed) *Weekly Report*, No. 109, VI. (15 September, 1917.)

were not only very urgent, but were of a specially difficult nature, involving intricate press-tool work. The machining of the drop forgings was also a difficult matter, as practically all the machining capacity of the country was occupied on other munitions. At first press work contractors sent these metal parts direct to aircraft firms on the authority of the department, but since about 40 firms were producing the parts, and there were 70 or 80 aircraft contractors requiring the parts, the daily clerical work became so great that the procedure broke down, and a central depôt was established in Birmingham, early in 1918, under the Central Stores Department, to receive and re-issue the stampings and pressings. The same system for providing metal parts was afterwards extended to the Bristol Fighter and D.H.9 machines.[1] In the spring of 1918 three new machines, the Vickers Bomber, Sopwith Snipe and D.H.10, were added to the programme. In order to supply fittings for these machines a slightly different policy was adopted, with a view to reducing the amount of detail work involved in centralisation. In the case of the Vickers Bomber, for instance, Messrs. Vickers became responsible for the supply and distribution of parts to main and spares contractors, under the supervision of the department. In connection with this scheme, Messrs. Vickers established a central store for distribution, as had been done for the Handley Page parts.

II. Timber.

The timbers chiefly used in aircraft construction are silver spruce and spruce substitutes, walnut, ash, poplar, mahogany and other hardwoods. With the exception of ash and poplar, all this timber was imported. Supplies of spruce, walnut and mahogany were at first obtained by contractors from timber merchants, in the ordinary way of commerce, import licences being recommended by the supply department. There existed in this country considerable stocks of naturally seasoned woods fit for aeronautical purposes, but by October, 1916, these stocks began to show signs of exhaustion and a shortage of timber was foreseen. It was agreed between the Admiralty and the Directorate of Military Aeronautics that the Admiralty should supply the requirements of both services, inspecting and shipping the timber as well as buying it,[2] and despatching consignments to contractors against requisitions approved by the supply department. This arrangement persisted until October, 1917.

The United States Aircraft Construction Board had before that time requisitioned the entire supply and production of silver spruce in the States, and were preparing to requisition walnut also. It was therefore arranged that for the future the Aeronautical Supplies Department should deal direct with the American Aircraft Construction Board for supplies of spruce and walnut from the United States, and with the Canadian Imperial Munitions Board for Canadian timber, while the Admiralty should continue to provide mahogany, which came from British Honduras and Nigeria.[3]

[1] (Printed) *Weekly Report*, No. 127, VIII, A. (26 January, 1918.)
[2] M.C. 69.
[3] *Ibid.*

The situation with regard to timber in September, 1917, was very grave. Next to labour, the supply of spruce was the most critical feature in supply.[1] The requirements of timber for 1918, exclusive of hardwoods and certain home-grown timber, were bound to come from Canada and the States. The dollar situation made purchase in British Columbia difficult,[2] and the lumber industry was not developed sufficiently in the northern part of the province, where most of the accessible spruce supplies were located, to supply a large output. Without liberal assistance from America it was accordingly impossible to obtain anything like the quantities required. The monthly demand from the United States to meet the requirements of Great Britain alone was 4,500 standards and the output for September was only 1,000 standards, 20 per cent. of the normal quantity.[3] The programme involved cutting about three times as much timber in America as had ever been cut before, but silver spruce was specially valuable because it was reliable and of the right weight and strength. It was difficult to change over to other timber for aircraft construction, as it involved so many trials to prove the suitability of substitutes, and if heavier scantlings were adopted, design was affected.

During October and November Admiralty contracts were at a standstill. Small shipments were made on private account, but of these small quantities, some were lost at sea and some were found to be unsuitable for aircraft work. Only by the strictest allocation of available supplies was it possible to prevent the closing of numerous wood-working firms. The first shipment with timber allocated by the Aircraft Construction Board arrived in December, 1917, containing 10 standards of silver spruce,[4] and for the four months ending 5 January, 1918, only 150 standards had arrived, against contracts placed on behalf of the British Government by the American Construction Board for over 40,000 standards of spruce and substitutes.[5]

Every effort was made to economise. A special timber economy inspector went round to the factories to enforce economy, and a system of travelling appeal inspectors was inaugurated to prevent the final rejection of timber which, though not up to specification, could possibly be used. Aeroplane spars were designed so that splices could be made if necessary, and laminated and box spars were introduced to use smaller sizes of spruce. Inspectors were sent to all lumber camps to select timber suitable for use in built-up spars. Diagrams were furnished to all aeronautical contractors with regard to the economical re-sawing of silver spruce, and the cutting up of plywood from small ends of large sheets.[6] The properties of other woods such as West Virginia spruce, Quebec spruce, Oregon pine, Canadian white pine, red and white deals were investigated and approved as substitutes for silver spruce, and used wherever possible. Great things were hoped from the substitution of cypress, but it proved to be a complete failure.

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[1] Hist. Rec./R/1960/8.
[2] M.C. 92.
[3] Hist. Rec./R/1960/8; 1960/5.
[4] (Printed) *Weekly Report*, No. 121, VIII A. (8 December, 1917.)
[5] *Ibid.* 124, VIII A. (5 January, 1918.)
[6] *Ibid.* 123, VIII A. (29 December, 1917.)

A big effort was made to use metal in the construction of the Avro training machine which was absorbing about one-third of the total wood supplies. A great deal of experimental work was done, but it proved so protracted that machines of metal construction were not produced in quantities during the war, and it was only by falling back upon the stock of timber imported under old contracts made by merchants independently of official channels, that requirements were met during the early months of 1918. In March assistance to shipments on private account was stopped, and the whole output of aeroplanes depended on the amount shipped by the American Board. Little or no timber was shipped during April owing to the restrictions of shipping space. During May shipments increased, but much of the timber sent did not come up to specification for solid spars, and some was entirely unsuitable for aeronautical work. Supplies sent by the Board were quite inadequate until the autumn of 1918, but by April, a built-up spar had been evolved superior to and safer than the solid spar and practically all machines were designed with them.[1] Moreover, other sources of supply had been developed. In September, 1917, the American authorities allowed the British War Mission to place contracts in North California and West Virginia and these produced about half a million feet per month of spruce. In October the Imperial Munitions Board decided to undertake the development of aeronautical timber supplies from British Columbia and the results were most satisfactory. Starting at one or two hundred thousand feet the output grew to over four million feet per month, and the spruce thus obtained proved to be superior to that produced in the States. Arrangements were also made to obtain all the Baltic spruce available.[2] These steps, combined with a most careful allocation of supplies, averted disaster. Meanwhile elaborate preparations were being made in America for production on an enormous scale and in November, 1918, the arrangements were so far advanced that all requirements were assured.

For the manufacture of propellers it was originally considered that the only suitable wood was black American walnut, but experiments have proved that mahogany of various types can be utilised and also alternate laminæ of mahogany and walnut. Large orders for walnut and mahogany were placed in the States, and the whole output of British Honduras was secured. A portion of the West African output was also secured. At the end of 1917 it became clear that the United States Government could not obtain from home sources sufficient quantities of walnut and mahogany for the construction of the propellers required to fill their aeroplane programme. The British Government agreed to cede their contracts in the States to the United States Government, and the West African market was developed by the United States in co-operation with the British Government.

There were two principal sources of supply of plywood, namely, English manufacturers and importations from Russia and America.

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[1] (Printed) *Weekly Report, passim.*
[2] HIST. REC./R/1960/5.

Demands for this class of timber increased very rapidly during 1918, the requirements rising from 9,000,000 ft. in 1917 to 25,000,000 in 1918. Every assistance was given to the small number of firms in this country whose manufacture was approved ; they increased their plant and were assisted in importing veneers from America and were thus enabled to double their output and meet the increased requirements. The raw material of plywood is veneer and to increase supplies of it, two British firms were given facilities to obtain the necessary machinery and supplies of birch logs both from this country and America. In 1917 one firm alone produced 14,000,000 ft. of veneers, increasing its production during 1918 to 20,000,000 ft.[1] Imported veneers and plywood were obtained under contracts placed in America through the Controller of Timber Supplies. The contracts placed in America amounted to 79,000,000 ft. of veneers and 21,500,000 ft. of plywood, but large supplies did not come forward before the end of the war.

In March, 1918, maximum prices for home-grown timber were fixed by the Board of Trade[2]: these prices related to standing timber, and to wood in the form of logs and planks. It concerned aircraft supply mainly in so far as the prices of ash were concerned. Control over the purchase and sale of both home-grown and imported timber was established by the Board of Trade in July, 1918,[3] and maximum prices were fixed for plywood in October.[4]

During the first two years of the war, timber inspection was confined to visual inspection of the stocks of naturally seasoned timber which existed in the country. Since these stocks were beginning to fail at the end of 1916, attention was devoted to the artificial seasoning (kiln-drying) of timber. In April, 1917, the Inspection Department began work on scientific lines. A kiln technologist was appointed to the staff and five timber drying kilns were started in the London district. The process was carried out on strictly controlled lines, charts being prepared by the Aeronautical Inspection Department showing precisely the temperatures and humidities to which aeronautical wood such as ash, mahogany and walnut were to be subjected during treatment. Theoretically, the Aeronautical Inspection Department's kiln-examiners were provided to ensure that the kiln-owner operated his drying room correctly. Since, however, most of the kiln-owners had little experience of the artificial seasoning of wood, the actual operation of the kilns was carried out by the Aeronautical Inspection Department's employees themselves and this procedure was regularised by the insertion of a clause in the kiln-owners' contracts. Though some 8,500,000 ft. super. of aeronautical timber was kiln-dried by the Inspection Department in this manner, not a single board was improperly handled or spoiled during the process.

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[1] (Printed) *Weekly Report*, No. 161, VII. (28 September, 1918.)
[2] *Home-Grown Timber Prices Order*, 25 March, 1918.
[3] *Timber Control Order*, 16 July, 1918.
[4] (Printed) *Weekly Report*, No. 161, VII. (28 September, 1918.)

Meanwhile the normal inspection of timber for aeronautical purposes was undergoing radical alterations. When kiln-drying was begun, it was necessary to overcome considerable prejudice against artificial seasoning in general and to this end the regular testing of timber (compression and bending tests) was begun at the Inspection Department's laboratories. These tests not only demonstrated that artificially seasoned timber was not inferior to the naturally seasoned product, but also that, in the general inspection of timber, physical testing as well as visual examination is necessary. A special test known as the plywood shear test was devised for plywood. When timber supplies became so short in 1917, efforts were made to bring into service any available supplies of red and White Sea red deals that could be found in this country. Very heavy demands had, however, already been made on the home stocks for general army purposes and inspection showed that only a very small percentage of the planks could be obtained sufficiently free from small knots and other defects to permit of their being used in aircraft.

III. Flax and Textiles, including Hangars.

(a) Flax and Flax Seed.

The supplies of high-grade Courtrai flax, from which aeroplane fabric was made, were entirely cut off in 1916, and all stocks of it were requisitioned by the War Office in January, 1917.[1] It became necessary to develop the growth of flax in the United Kingdom, not only for the requirements of our own Flying Services, but also to supply the needs of the Allies. Flax had been grown to a considerable extent in Ireland before the war and Irish looms were capable of producing fabric of the necessary high quality. The Scotch mills and factories produced yarn and cloth of a coarser quality and their machinery was not adapted to make the fine material required. To ensure an adequate supply of linen fabric, control both of the crop and the manufacture were found necessary in 1917. In August, the Ministry of Munitions accordingly took over the whole of the Irish flax crop grown during 1917,[2] at fixed graded prices and allocated it to spinners for conversion into aeroplane yarns. The administration and control were placed in the hands of the Controller of Aeronautical Supplies, and, after consultation with the leading members of all the trades concerned, it was decided to form a committee, the Flax Supplies Committee, representative of all the interests involved to act under an Administrator as a purchasing and advisory committee on behalf of the department. It was decided to adopt as far as possible the ordinary market procedure for the purchase of flax, and a large staff of inspectors, graders and market clerks was engaged. The committee received every assistance from all the flax trades in Ireland and firms were pleased to put at the disposal of the committee the services, for the time being, of their expert buyers. Arrangements were made during September, 1917, for

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[1] *Courtrai Flax* (*Control*) *Notice*, 5 January, 1917.
[2] For the terms of the Order see Appendix I.

the opening of flax markets throughout the North of Ireland. Flax inspectors were empowered at the markets to issue cheques in payment for flax on behalf of the Administrator. From the beginning of operations on 1 September, 1917, to the end of the first financial year, viz., 31 August, 1918, 15,017 tons of flax were purchased, allocated and sent by rail to spinners in Ireland and Scotland. The value of the flax purchased was £3,378,225 and the total turnover, in cash, including expenses, was £3,590,850.[1] Special banking arrangements had to be made in Ireland for the handling of the vast numbers of cheques involved and for the cashing of them at the market towns. The number of cheques issued during the year was 65,000. In addition to the Purchasing Committee the Government also formed, at the commencement of operations, an Allocation Committee, consisting of four spinners, together with the Government Administrator and Deputy Administrator. A census of the stocks of all flax in the hands of spinners was carefully taken and tabulated, and the Allocation Committee decided to whom flax was to be sold. This Allocation Committee was, at the end of 1917, merged into the Flax Control Board (Irish Sub-Committee) of the War Office, which was formed in October, 1917, and took over the work of allocation. As from 12 January, 1918, the Flax Control Board took entire control of the flax manufacturing industry, and, from that time until the Armistice was signed, spinners were not allowed to manufacture any yarns except in fulfilment of Government orders, and flax was allocated to them on this basis.[2]

In February, 1918, the flax crop for the year 1918 was also taken over by the Ministry of Munitions at fixed prices somewhat higher than those fixed for the 1917 crop.[3] The Department also purchased from the Purchase Department of the War Office all foreign flax (excluding Russian) landed by that department in Ireland. The expenses of working were recovered by a small additional charge added to the purchase price of the flax, and it is of interest to note that the department succeeded in buying flax, on behalf of spinners, at a less cost per stone to them than they were in the habit of paying to flax merchants, who bought on commission.

In order to separate the fibre from the stem it is necessary for the flax to go through a process called scutching. Certain lower grades of yarn are made from the tow resulting from rescutching. In February, 1918, control was established over the rescutched tow off the Irish 1917 flax crop[4]; and in October possession was also taken of the tow from the 1918 crop.[5] It was also decided, early in 1918, to control every scutch mill in Ireland, and from 1 July no scutching was permitted except under Government licence.[6] Inspectors were

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[1] Hist. Rec./H/1960/2.
[2] *The Flax (Restriction of Consumption) Order*, 27 December, 1917.
[3] *Flax (Irish Crop) Order*, 8 February, 1918.
[4] For the terms of the Order see Appendix II.
[5] Rescutched Tow (No. 2) Order, 1918.
[6] For terms of Order see Appendix III.

appointed and licences were issued to those mills which were fit to scutch flax properly and economically, but were refused in cases where repairs were necessary. This led to the complete overhaul of about 150 scutch mills in Ireland, and the result has been a vast improvement in the scutching of flax. To ensure that all the flax coming forward should be scutched, mill owners were encouraged to employ apprentices to the scutching trade by the payment of bonuses for each apprentice trained. The bonus only applied when apprentices were specially approved by the Flax Supplies Committee, which was thus able to refuse the benefit where mills were not properly equipped. The inspection necessary and all the executive work required under the scheme were in the hands of the Department of Aircraft Production.

Supplies of flax seed from abroad were purchased by the War Office, and by an Order of the Army Council, dated 12 July, 1917, one-eighth of the Irish flax crop of 1917 was reserved for seed, and instructions were issued for its proper drying and deseeding.[1] This seed was taken possession of by the Ministry of Munitions in November, and the sale of imported flax was controlled in December.[2]

In August, 1918, it was decided that a Ministry of Munitions Advisory Flax Seed Committee should be formed, under the chairmanship of the Administrator of the Flax Supplies Committee, to regulate and control, under the direction of the Flax Control Board, the whole of the supply of imported flax seed into Ireland during the season 1918-19. The War Office remained responsible for the purchase of foreign seed, but the Ministry became financially responsible for all flax seed operations in Ireland, *i.e.*, the provision of funds for the flax seed saving scheme initiated by the War Office, the purchase and distribution and sale of Irish seed, and the distribution and sale of foreign seed in Ireland.[3] The centralisation of the purchasing and distribution of flax seed assured an ample supply for Ireland, and the action of the British Government in purchasing seed and encouraging its growth in Canada, Japan, and elsewhere, enabled the department, after the signing of the Armistice, to supply Belgium, France, and Serbia with their requirements for reconstructing their flax industries. In March, 1919, the administration of the Irish flax crop was transferred to the Board of Trade.

(*b*) LINEN.

During the first years of the war all fabric used in aeroplane construction was linen fabric manufactured in Ireland. By the middle of 1916 the War Department was making bulk purchases of linen for supply to aeroplane contractors, and it was soon found necessary to assume complete control, the Admiralty agreeing to purchase all their linen fabric through the Department of Military Aeronautics.[4] In

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[1] *Flax Seed (Ireland) Order*, 1917: Regulations, dated 19 July, 1917, prescribed by Department of Agriculture and Technical Instruction for Ireland, under the Flax Seed (Ireland) Order, 1917, as to the saving of flax seed.

[2] *Flax Seed (Control) Notice*, 1917: *Sale of Flax Seed (Ireland) Order*, 1917.

[3] M/General No. /187.

[4] For terms of Order see Appendix IV.

December the War Department took control of the purchase and sale of linen yarn, and in January of the spinning thereof.[1] There was some hesitation about taking over the whole of the supplies of linen from the weavers, for supply to aeroplane contractors, but in the spring of 1917 it was decided to do this, and prices were fixed for linen fabric as well as for yarn.[2] By July costings investigations had been made both for spinning and weaving, and prices for linen as supplied to aeroplane firms were fixed, based upon 2s. 8d. per square yard for solid fabric and 1s. 9d. per square yard for spaced fabric. This price included inspection and delivery. Prices were also fixed for payment to the weavers, based upon the fixed prices of yarn.[3] In February, 1918, all prices were readjusted for the 1918 supplies.[4] Regulations as to weaving were issued in April, permits being required for all work. The use for civil work of any yarns suitable for aeroplane fabric was forbidden, and tow or cotton weft was to be used in place of line wherever practicable. No warp tows requiring line weft were for the future to be put in process.[5] In August, 1918, prices were once more revised.[6]

In order to obtain adequate supplies of fabric it was found necessary in the latter part of 1917 to approach various manufacturers in the Scottish district with the request that they should endeavour to manufacture this type of linen. The majority of the firms approached were damask manufacturers, with very little experience in the weaving of plain fabrics. Assistance and information were, however, given by the Aeronautical Inspection Department to these manufacturers, and in a short time they were fully engaged in producing large quantities of very satisfactory material.

The control of flax led to great changes in the linen trade. Weavers were not very amenable at first, but subsequently their co-operation was obtained, and in a few instances most valuable expert assistance was given to the department. This was particularly manifested in assisting the department in selecting yarns and in advising as to new makes of cloth to increase the quantity of the right grade. To illustrate how enormously the output was increased, it may be stated that during the last three months of 1917 only 2,000,000 yards of linen cloth were produced, but in 1918 over 59,000,000 yards of cloth were turned out of the looms.

(c) Cotton Fabric.

Owing to the occupation of the Courtrai district by the enemy, the collapse of Russia in 1917, and the uncertainty of the flax crop in Ireland, it was decided to try cotton as a substitute for linen, as an insurance of supplies of fabric for aircraft. No definite specification existed and the early results were far from satisfactory. In January, 1918, a definite specification and a suitable scouring process were

[1] A.S. 28438/1917.
[2] A.S. 4347/1917.
[3] A.S. 22508/1917, 24682/1918, 5930/1918.
[4] A.S. 31100/1917.
[5] A.S. 24682/1918.
[6] A.S. 31100/1917.

decided on, and fresh contracts were placed, the results being very satisfactory. This fabric was at first used only on training machines, in order that it might be tested. In March, 1918, a specification used by the Americans was adopted, and the cloth manufactured was so good as to establish the fact that cotton was capable of being turned out in a cloth of such weight and strength as to compare very favourably with linen. Orders for 14,000,000 yards were placed, and the cotton looms in Lancashire immediately began adding to the stock of fabric required for a reserve so vitally important to the successful prosecution of the war.

A Royal Naval Air Service depôt had already been established in Manchester, in the autumn of 1914, to deal with the whole supply of cotton for aeronautical purposes. At a conference in July, 1916, it was decided that the War Office should be responsible for their own supplies of cotton for kite-balloons, on account of the rapid increase in the production of balloons for the use of the Army. This divided control continued when the Department of Aeronautical Supplies became responsible for the supply of kite-balloons, the department taking over the responsibilities of the War Office with regard to supplies of cotton fabric.[1] It was agreed in August, 1917, that the Admiralty should provide fabric to meet the requirements of kite-balloons for both Services since they were the larger users, but the demand for aeroplane cotton fabric which arose towards the end of 1917 gave rise to fresh requirements by the Department of Aeronautical Supplies[2], which were met through the War Office Contracts Department.

In February, 1918, the procedure as regards the purchase and supply of cotton fabric for aeronautical purposes was as follows :—Demands for cotton for heavier-than-air machines were put up to the Aeronautical Contracts Department, and they deputed the purchase to the War Office Contracts Department. The Manchester production officer was responsible for output, and the Aeronautical Inspection Department for inspection. Demands for cotton fabric for balloons were put up to the Admiralty Contracts Department, and the Admiralty purchased, inspected, and were responsible for production. A Trade Committee had been established at Manchester in January under the ægis of the Admiralty to allocate orders for the respective heavier and lighter than air machine requirements. Total demands were put before this committee and it was their duty to see that a fair allocation of looms was made.[3]

The approximate requirements of the different departments at that time were :—Admiralty, 80,000 yards weekly ; War Office, 4,000,000 yards weekly ; Department of Aircraft Production, 1,175,000 yards weekly.

It was suggested that supply should be centralised in one authority, the large requirements of the War Office clearly indicating that Department as the most suitable to undertake supply. The

[1] A.S. 17544/1917. [2] A.S. 26502/1917. [3] A.S. 17544/1917.

Admiralty would not agree to this, on the ground that special knowledge was required for the purchase of fabric suitable for airships and kite balloons, but the matter was not allowed to rest and was referred in March to the War Priorities Committee.[1] It was then arranged that the War Office should assume responsibility for supplying and proofing all cotton fabric. Owing to various difficulties, the actual transfer was not made until 21 May, when supply both for the Air Service and for the Allies was taken over by the Raw Materials Branch of the War Office.[2] It had been recommended in March that the War Office should also undertake inspection and technical and research work in connection with cotton fabric, but that Department raised objections on the ground that a supply department should not inspect its own products.[3] The Director-General of Aircraft Production pointed out the danger of having two independent systems of inspection for the same product, often the output of the same firm and the same machine, and suggested the formation of a central department under the War Office, in which all the Departments concerned should be represented, to develop technical work, and co-ordinate the work already done at various centres by different Departments.[4] This scheme was rejected by the War Office, and the work as far as it affected the Department of Aircraft Production passed to the Aeronautical Inspection Department.

(*d*) Canvas and Hangars.

Towards the end of 1916 it became apparent that much larger structures would have to be provided for housing aeroplanes than the tents then in use. These were the R.E.7 and R.A.F. tents, which had the great advantage of being exceptionally portable, but suffered from the disadvantage of being unable to withstand severe weather and high winds. Their sizes, too, limited their usefulness. The R.E.7 was 60 ft. by 38 ft. and 20 ft. high at the centre; the R.A.F. was 53 ft. by 43 ft., and 19 ft. 6 in. high at the centre. It was found after considerable use that the R.E.7, because of its lesser weight and simpler construction, was the better tent of the two. Consequently the R.A.F. tent soon became obsolete. The R.E.7 still remains one of the most useful structures for housing small aeroplanes. Numerous designs for new and larger structures were proposed, but it was not until Monsieur Hervieu, of Paris, gave his invaluable assistance that a satisfactory structure was decided on. He designed several hangars, the most successful of which was the Hervieu III. He also, in conjunction with Monsieur Bessoneau, designed the Bessoneau hangar. These remain two of the best types. The Bessoneau is 79 ft. wide by 66 ft. 3 in. deep, 13 ft. 2 in. high at the eaves and 17 ft. 2 in. at the centre. The Hervieu III is still larger, being 80 ft. wide by 80 ft. deep and 20 ft. high along the entire front. When these two designs were finally approved, steps had to be taken to find sources of supply. The construction of hangars calls for the co-operation of many trades. The frame is a wooden one with joints strengthened by mild steel

[1] A.S. 26502/1917.
[2] C.R.V./Gen./2537.
[3] A.S. 17096/1917.
[4] *Ibid.*

plates; the cover is made of waterproof canvas; the stays are wire ropes with special metal fittings attached to, and suspended from, the stanchions and fastened to the ground by screw pickets. To find firms capable of supplying all these different parts was an extremely difficult matter, and before capacity was found adequate to meet the demand, the whole country had to be scoured. Early in 1917 the only known source of supply for metal fittings was a small firm in the East End of London, which before the war was doing ship chandling business. Supplies from it were so small that the few hangars then produced were held up, and owing partly to this and partly to the difficulty of obtaining timber and canvas for covers, during 1917, the demand for large hangars was not satisfied to more than about 40 per cent. In January, 1917, some difficulty was experienced by contractors in obtaining long lengths of timber, but the output of frames was then about 50 per week. The fittings were still a limiting factor, their output being then only 35 per week. There was, however, some stock of fittings and arrangements were being made with new firms to produce them.[1] Several new firms were also found about this time to construct frames. Further proofers were added to the list, supplies soon began to creep up steadily, and eventually there was a considerable reserve of nearly all types. The increase in the number of firms introduced competition, and it was possible to reduce the cost of the hangars on an average by 20 per cent., despite the fact that the cost of labour had advanced during the year and the price of all materials had gone up. With improvements in the sources of supply, and the finding of more competent firms, it was possible to experiment on types of hangars larger than the Bessoneau and the Hervieu. Eventually the Hervieu VI was built, 130 ft. by 66 ft. 6 in. and 25 ft. high, and the Hervieu VIII, 79 ft. by 66 ft. and 25 ft. high. The maximum size for a satisfactory structure was reached by the Richards B hangar which was 130 ft. by 60 ft. and 25 ft. high.

Up to the middle of 1917 the type of canvas in use for aeroplane tents was the ordinary flax tent duck (War Office standard, 27 in., 10½ oz.). Covers made from this canvas were used to cover the R.A.F., R.E., and B.E. light tents. With the advent of the larger hangars a heavier and stronger type of canvas was required. A cloth of a more or less standard make, 36 in. wide and weighing 18 oz. per square yard, was adopted. It was at first decided that this should be made from flax with a breaking strain of not less than 230 lb. per inch strip. On account of the shortage of flax, however, the standard could not be maintained. Ever increasing quantities were required and to add to the difficulties the size of hangars was constantly being increased. This necessitated an increase of the weight of the canvas until 24 to 25 oz. per square yard was reached. Great difficulties were encountered in obtaining the canvas, and matters were complicated because all demands had to be passed through the Textile Section of the War Department. This was unavoidable owing to the fact that the War Department was ordering large quantities of canvas for other branches

[1] (Printed) *Weekly Report*, No. 124, VIII A. (5 January, 1918.)

of the Service, and unity of control of supplies was imperative. For the nine months ending September, 1917, the total yardage of canvas dealt with by this section of the Materials Branch was only 1,250,000 yards, and this was quite inadequate for the demands. After urgent representations to the War Department, supplies improved, and between September 1917 and September 1918 over 9,500,000 yards were obtained, and it was possible to keep pace with demands. Towards the end of the war, supplies of flax canvas fell far short of demands, and a heavy cotton duck of a weight of 20 to 24 oz. per square yard was brought into use, but it was not satisfactory. It was found to crack easily after being folded for transport, and it was thus useless for protecting aeroplanes against bad weather.

All canvas used for hangar covers had to be proofed and dyed. Experiments to obtain a standard specification for camouflaging continued without success until June 1918, when it was decided to dye the fabric a shade of dull myrtle green, which from all reports proved to be the most satisfactory. In addition to the demands for Great Britain, Allied demands for 2,500,000 yards were dealt with, but a great deal of the canvas sent out had to be of the cotton duck variety.

The same sub-section of the Materials Branch dealt also with kite-balloon cordage, ropes, etc. As in most war supplies, there was a serious shortage in September, 1917. Manufacturers, especially in the Bridport district, were approached by the department and they gave their assistance readily and eagerly. Supplies steadily increased and kept pace with the output of balloons. Some idea of the quantities dealt with is given by the fact that one contract demand for rope and cordage gave a total of 30,700 miles. The sub-section also dealt with tapes and threads required for binding the struts of aeroplanes and stitching the fabric covering the wings. Here again supplies kept pace with demands, though a decision taken in September, 1918, to bind the whole length of the struts, instead of the ends and joints only, put a great strain upon the supply department.[1]

A difficulty which had to be surmounted in connection with these portable buildings was the transport from various parts of England to the Channel ports. In order to carry one Hervieu III. hangar, 15 ordinary trucks were required at first, but, by a little rearrangement, the number was gradually reduced to nine. Later on, the Railway Companies were able to supply special trucks built for the purpose of handling the large sections of these hangars. By taking advantage of the experience of thoroughly qualified packers, three hangars could be stowed in two special and 12 ordinary trucks.

(*e*) Inspection of Textiles.

During the first year of the war all textile materials used in aeronautical construction were tested and inspected at the Royal Aircraft Factory. Early in 1916, however, it was decided that this work should be taken over by the Aeronautical Inspection Department

[1] (Printed) *Weekly Report*, No. 158, VII. (7 September, 1918.)

and an organisation was built up accordingly. A textile specialist was placed in charge of the work and inspection proceeded along normal Inspection Department lines. Since all aeroplane fabric was at that time linen manufactured in Ireland, inspection began in Belfast, the testing being carried out by Inspection Department staff at the public testing and conditioning house in that city. The inspection at Belfast consisted of selective examination, the visual examination being left to the examiner stationed at aircraft works, who advised as to the treatment of any defects. It was, however, later found desirable that all fabric inspection should take place in Ireland, and every piece of fabric was visually inspected in Belfast. Towards the end of 1917 the amount of testing in the Irish districts had increased to such an extent that it was decided to establish an Aeronautical Inspection Department test house in Belfast, and by the end of the year it was completed and equipped. Just before the signing of the Armistice the average amount of fabric inspected in the Irish district amounted to 1,500,000 square yards per week.

By the beginning of 1918 the output of aeroplane fabric in the Scottish district had become so great that it was found necessary to establish an inspection bond and test room at the Dunfermline Technical School. The cotton fabric manufactured in Lancashire was inspected at a Central Stores Department store in Bolton, at which place an inspection bond and testing laboratory were established. In November, 1918, the average amount of cotton fabric inspected per week amounted to 500,000 square yards.

Prior to December, 1917, all the tape used for the taping and binding of fabric-covered aircraft components was supplied to aircraft constructors in the form of missed-warp fabric and was cut up into tape by their own employees. In addition to being very expensive, this cutting was done in many cases in a very unsatisfactory manner, and in August, 1917, the Aeronautical Inspection Department put forward a suggestion that the tape should be cut by the missed-warp manufacturers themselves. This could not be conveniently arranged, so the Aeronautical Inspection Department offered to instal machines at their test house in Belfast and to cut tape there. A Cameron tape-cutting machine was installed there in December, 1917. The tape cut was so satisfactory that demand for supplies soon exceeded the capacity of the machine and in the early part of 1918 two additional machines were obtained and one was added to the equipment at Belfast and the other installed at Bolton. In addition to providing a much cheaper and better cut tape from missed-warp fabric, it was found possible to increase supplies of tape very greatly by using the Cameron cutters for the manufacture of tape having serrated edges. Tape of this kind was cut from solid fabric unsuitable for other aircraft purposes.

In addition to aeroplane fabric, the Aeronautical Inspection Department inspected rubber-proofed fabrics for kite-balloons, hangar canvas, ropes and cordage, sewing thread and parachute silk, and drew up specifications for standard textiles, ropes and cordage.

IV. Dope.

A problem which presented itself for solution very early in the history of aviation was the prevention of the passage of air through the fabric, since this destroyed the lifting power of the wing. The wings were covered with some kind of paste like tapioca, and in dry weather this was found effective. Moisture washed the paste off, with the result that the aeroplane descended with unpleasant rapidity. Beeswax and glue were also tried and the wings were rubbed and polished. The moisture of the air caused another difficulty, *i.e.*, the sagging of the fabric. Opinion is now divided as to whether moderate slackness is injurious, as it only has an ill effect when it alters the shape of the wing sufficiently to change its aerodynamical properties. However, pilots feel strongly on the subject of the tautness of their aeroplane wings and the question becomes one of *morale*. Ever since flying became general some means of tightening the fabric has been used: hence the evolution of aeroplane "dope," a term of American origin, first used because it gave the fabric qualities it did not naturally possess and only subsequently associated with the injurious effects which it was afterwards found to have on the workers.

The base of the dope is liquid cotton applied so that on drying it fills the interstices of the fabric with a similar substance. The base of the earliest dope was a low nitrated cellulose, which is formed by the action of nitric and sulphuric acids on cellulose (cotton) and this is still used in titanine and the dope from the German Albatross. Cellulose nitrate being highly inflammable, a fire-proofing substance, triphenyl phosphate, was added. These were dissolved in a light solvent, acetone, a heavy solvent, amyl acetate with adulterants, benzol and methylated spirit. Tetrachlorethane was also used as a heavy solvent, but it was found to have injurious effects on the workers and in later dopes was not used. Owing to the inflammability of nitro-cellulose dopes, they were superseded by acetate dopes, consisting of cellulose acetate with benzyl alcohol as a heavy solvent and other ingredients as in nitro-cellulose dope.

It was found that cellulose acetate had all the advantages of nitro-cellulose, and dope formed from it possesses high qualities such as non-inflammability, pliability, toughness, clarity and durability. Benzyl alcohol and tetrachlorethane are the softening ingredients. They do not readily volatilise but remain in the film and prevent brittleness. Benzyl alcohol is prepared from toluene, a by-product of coal tar, and in order to economise toluene, which forms the raw material for the manufacture of T.N.T., various substitutes have been suggested for it.[1] The early attempts proved unsatisfactory, but later triacetin was used with great success. Benzyl alcohol is more volatile than triacetin, and dopes containing it give greater tautening effect for an equal weight of deposit. Triacetin remains longer in the film and triacetin dopes have a longer life, especially in hot climates.[2]

[1] Hist. Rec./R/1500/4, p. 37.
[2] A.S. 27861/1917.

Many alterations in dope during the war have been caused by scarcity of solvents. The best solvent, acetone, was in great demand in the manufacture of propellants.[1] Supplies came almost entirely from America, where market conditions were extremely difficult, particularly in the spring of 1915. Attempts were then made to find acetone substitutes. Two of them, methyl-ethyl-ketone and methyl-acetone, are in common use and methyl acetate is also used.

While dope meets the needs of the situation as regards tautness it does not prevent the weathering of the fabric. Linen suffers a marked decrease in resistance to tensile stress when exposed for any length of time to sunlight. This effect is produced by the ultra-violet rays, and accordingly efforts were made to provide a varnish pigmented in such a way as to cut off these rays. Such a varnish was successfully evolved at the Royal Aircraft Factory, and there also was solved the difficult problem of introducing pigment into the dope itself, the colouring matter generally used being ochre (oxide of iron). A considerable amount of protection is secured by a clear varnish, of which three types have been tried, resin spirit, linseed oil and nitro-cellulose. The last proved the most satisfactory and is very similar to dope, but has castor oil or its substitute in its composition.

Cellulose acetate is made from cellulose, which is formed into paper (celluloid), torn into shreds, and treated with an acetylating mixture consisting of acetic anhydrid, acetic acid and sulphuric acid. Benzyl alcohol manufacture consists in the chlorination of toluene, to give benzyl chloride. The hydrolisation of this in the presence of alkali results in the production of benzyl alcohol. Acetone has been prepared during the war by several different methods. The greater part was obtained by wood distillation. The acetic acid resulting from the distillation is treated with milk of lime and yields acetate of lime, by the distillation of which either acetone or methyl-ethyl-ketone are obtained. Large quantities have been obtained by fermentation of maize. Acetone may also be made by the conversion of calcium carbide and alcohol by means of catalysis. It will be seen that acetic acid plays a large part in the manufacture of dope.

The making of cellulose acetate originated in Germany, and at the beginning of the war our only sources of supply were one firm in Switzerland and a small firm in France (Messrs. Usines du Rhône). At first the dope-makers purchased their materials independently and there was no check on the economical use of them. By the middle of 1915 there was a shortage of cellulose acetate, and from this time the bulk of the purchases were made by the War Department, not only for the Royal Aircraft Factory and their own contractors, but in some cases for Admiralty contractors also. Before the beginning of 1917 control over the supply of cellulose acetate was complete.[2]

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[1] See Vol. VII, Part IV, Chap. IV, for a general account of the supply of acetone.

[2] 87/A/19.

In July, 1915, tenders were issued by the Directorate of Military Aeronautics for 100 tons[1] of cellulose acetate to be made in England. The only tenderer was Dr. Dreyfus, of the Cellonite Company, Basle. He reserved the right to deliver 50 per cent. of the total quantity from Switzerland. This being the only tender, it was accepted. Dr. Dreyfus then negotiated for the purchase of the works of the Safety Celluloid Company, Willesden, a company unable to manufacture, on account of the return of their German manager on the outbreak of war, but the capacity of these works proved to be insufficient. After the signature of the contract, Dr. Dreyfus pointed out the difficulty in raising capital for such an enterprise unless it was guaranteed against war taxation. A loan was suggested as an alternative, the terms put forward being that a limited company should be formed to acquire the Dreyfus patents, and on subscription of £15,000 the War Office should advance £25,000 at 5 per cent. interest, secured as a first mortgage. Dr. Dreyfus failed to float the contract on these terms, and returned to Switzerland. He was then approached by certain financiers who had already, without success, tried to manufacture cellulose acetate in this country, and the British Cellulose and Chemical Manufacturing Company was formed on 18 March, 1916, for the erection of plant for the production, by the Dreyfus process, of acetate of cellulose, methyl acetate, and other chemicals. The promoters of the company again approached the War Office with a request for exemption from excess profits duty, to which Dr. Dreyfus attached great importance, but several months passed and nothing was done. Meanwhile, plans were being prepared for the proposed factory. A site was purchased at Spondon, near Derby, and building operations began in August, 1916.[2]

The production of cellulose acetate in this country was considered so important[3] that steps were taken to aid the company. Negotiations were prolonged until November, 1916, when the following offer by the War Office was accepted by the company:—Capital expenditure incurred upon plant during the war was to be refunded up to a maximum equal to excess profits duty actually charged in respect of each year's working during five years from the company's formation. The conditions of this were that reasonable prices should be fixed by discussion; that during the war orders should be accepted only from the Government or Allies, or private firms for supplies for the Government; and that after the war orders should be unrestricted, provided the needs of the Government were met.[4]

In January, 1917, after samples of its products had been passed by the Inspection Department, the company obtained its first direct contract for the supply of 40 tons of acetate of cellulose, at the rate of one ton per day, commencing when the factory was ready. By

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[1] The estimated requirement of the War Department for cellulose acetate for the year ending September, 1916, was 43 tons. (87/A/19.)

[2] *Report of British Cellulose Enquiry Committee*, 1919. Cmd. 306.

[3] 87/A/520.

[4] 87/A/698.

this time the aeronautical programme was increasing with great rapidity, and it became urgently necessary to safeguard future supplies. Since no other British source of supply appeared to offer any prospect of early production, assistance was given to the company in priority and labour for completing their new works,[1] and the first ton of acetate from Spondon passed inspection in April, 1917.[2]

At about this time a shortage of acetone was anticipated, and the company put forward proposals for the manufacture of methyl acetate as an alternative solvent for acetone, and expressed its willingness, if supported with priorities and sufficiently large contracts, to lay down plant for the production of synthetic acetic acid, which would involve the erection of carbide and electric power plant. Cellulose acetate of good quality was being produced in May, and in June contracts for 25 tons a month of acetate, as well as for 2,500 tons of acetone and methyl acetate, were arranged. The Ministry agreed in August to lend £200,000 capital at 6 per cent. interest, secured on a first mortgage, to finance the extensions required. Sir William Weir sanctioned the scheme, on the ground that Great Britain should be independent of foreign supplies of carbide, and the scheme was passed by the Munitions Works Board in January, 1918.[3]

Meantime, in July, 1917, supplies of cellulose acetate were the cause of great anxiety, since the French had commandeered the whole output of Messrs. Usines du Rhône for July, but the output of the British Cellulose Company enabled the department to carry on.[4] The company's carbide works had failed to produce acetic acid, and as they had not placed orders to cover their manufacture of cellulose acetate, this failure caused a sudden demand for acetic acid for dope manufacture, which the supply situation made it difficult to meet. The Trench Warfare Supply Department needed acetic acid for the manufacture of lachrymatory gas, and as contractors had been left to purchase their own materials, and competed against one another through brokers and merchants, the price had been forced up, and speculators had entered the market. By August, 1917, supplies were so short that the use of nitro-dope had to be reconsidered, and it was sanctioned for use on machines employed for home service where the danger from incendiary bullets did not arise; and later in the year its use was extended to fuselages and nacelles of all aeroplanes.[5] Manufacturing capacity was secured to produce, if necessary, sufficient nitro-dope to meet the whole programme in case of the failure of acetate dope. It then became necessary to conserve nitro-cellulose for dope purposes, and the question of employing oil varnishes in place of nitro-cellulose covers was taken up.[6]

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[1] *Report of British Cellulose Enquiry Committee*, 1919. Cmd. 306.
[2] (Printed) *Weekly Report*, No. 89, IV. (28 April, 1917.)
[3] A.S. 8671/105/1917.
[4] (Printed) *Weekly Report*, No. 99, VI (7 July, 1917); No. 100, VI (14 July, 1917).
[5] *Ibid.*, No. 105, VI (18 August, 1917); No. 108, VI (8 September, 1917); No. 112, VI (6 October, 1917).
[6] *Ibid.*, No. 110, VI (22 September, 1917).

In September, the Trench Warfare Supply Department established control over supplies of acetic acid with a view to meeting the needs of both departments. A month later the supply of acetic acid was taken over by the Propellants Branch of the Department of Explosives Supply, since that branch had arranged to supply acetic acid from synthetic acetone factories.[1] The Department of Aeronautical Supplies issued at the end of October a requirement for 1918, covering 16,350 tons of acetic acid as a maximum, if methyl acetate was used to replace wood distillation solvents, the quantity set aside for methyl acetate being 10,000 tons. It was impossible to increase supplies from America without upsetting the production of solvents, but the synthetic acetic acid produced by two ventures, one Canadian and one British, was, after redistillation, found suitable for cellulose acetate manufacture, and the British Cellulose Company, though unable to produce the synthetic acid, were able to carry out redistillation at their works. Early in 1918 changes in the nature of the poison gases required eliminated trench warfare requirements, so that supplies of acetic acid to meet the needs of the manufacture of cellulose acetate were assured. This country became independent of France and Switzerland for supplies early in 1918, and in February nitro-dope was dispensed with. In July it was possible to supply the Americans with 25 tons of cellulose acetate per month, despite the fact that in the meantime the demand for dope had been 25 per cent. more than was allowed for in the programme.[2]

The control extended over supplies of acetic acid in September, 1917, led to a claim on the part of the British Cellulose Company for increased prices for their products in new contracts for which they were negotiating in the early months of 1918. The price of acetic acid had been considerably raised since September and the cost of labour had also increased, but the Ministry was unable to meet the claims of the company, which represented an increase of 50 per cent. on the original contract. The outcome of protracted negotiations was the cancellation of the financial agreement of November, 1916,[3] and a settlement of new terms in June, 1918. By this agreement all existing contracts were cancelled, and fresh contracts were arranged on the basis of periodical average cost plus a fixed profit and a proportion after the first six months of any saving in cost, fixed rates of depreciation on building and plant being allowed for the purpose of ascertaining the average cost. The Ministry undertook to make loans to the company against its expenditure on electric plant, and also to lend a fixed percentage of the company's approved war capital expenditure on buildings and other plant up to the end of 1918, such loan to bear interest at the rate of 1 per cent. above bank-rate, with a minimum of 5 per cent. per annum, to be

[1] Vol. VII, Part IV, Chap. IV.
[2] Hist. Rec./H/1960/2.
[3] The concession as to excess profits duty was actually a dead letter, as the company had made no profits at all.

repayable within five years from the date of the agreement. Pursuant to these provisions the Ministry had, up to October, 1918, advanced the sum of £900,000.[1]

Steps were taken to economise and conserve solvents in the summer of 1917, when a world shortage appeared to be imminent,[2] putting the aeroplane programmes of all the Allies in jeopardy. One method adopted was to increase the concentration of the solution, and to use fewer coats, but it is difficult to get the right degree of penetration, adhesion and uniformity of covering, with the stronger solution. Experimental attempts were made to recover solvents. One suggestion was to apply the first coat of dope at the linen finishers or some central station by passing the fabric through a closed bath of dope, so that the whole of the solvent could be recovered. Better penetration is secured by this means. With a view to eliminating the loss of solvent while handling the dope, cans were introduced where a minimum of surface is exposed to the air, by devices of the ordinary ink-well type.[3]

The efforts of the British and United States Governments for increasing output in America ensured fairly adequate supplies of solvent in 1918. Some economy in acetone was effected by the use of methyl-ethyl-ketone for nitro-dope, but the adoption of methyl acetate as a substitute was retarded by the difficulties of production met by the five firms engaged in manufacture.[4] Methyl-ethyl-ketone was produced from butyl alcohol, a by-product in the manufacture of acetone by the Weizmann fermentation process which was developed during 1917.[5]

The softening ingredients chiefly used in dope manufacture have been tetrachlorethane, benzyl alcohol and triacetin. Tetrachlorethane was used in the earlier dopes, but its poisonous properties and the belief that it had an injurious effect upon the fabric led to a search for substitutes for it even before the war. An entirely satisfactory substitute was found in benzyl alcohol, a by-product of the dye industry, and the dope known as Raftite was manufactured with this ingredient as softener. After the outbreak of war supplies of benzyl alcohol ceased, and it was then discovered that the Germans alone knew the secret of its manufacture. Investigations were immediately undertaken at the Royal Aircraft Factory with a view to finding its composition, but in the meantime, since stocks soon failed, recourse had to be had to tetrachlorethane dopes, since dopes made without a softener cracked and were useless. The amount of tetrachlorethane was reduced as far as possible and various precautions were taken against the poisoning of the workers.[6] Though benzyl alcohol had been successfully manufactured in small quantities at the Royal Aircraft

[1] *Report of British Cellulose Enquiry Committee*, 1919. Cmd. 306; 87/A/19.
[2] Vol. VII, Part IV, Chap. IV.
[3] D.M.R.S. 467.
[4] (Printed) *Weekly Report*, No. 146, VII. (15 June, 1917.)
[5] Vol. VII, Part IV, Chap. IV.
[6] *Minutes of the Committee on the Administration and Command of the Royal Flying Corps*, 20th Day, 12 July, 1916.

Factory at an early period in the war, some time elapsed before the necessary plant was evolved and made available for manufacture by the trade. The limited resources of the factory were never able to overtake the demand, and after two years of war the tetrachlorethane dopes were still in use, though their poisonous properties had been reduced to a minimum. By the middle of 1917 three plants were at work on the production of benzyl alcohol and good supplies were coming forward.[1] The increased demands at the end of the year led to further efforts to obtain substitutes. Triacetin was used temporarily, and triphenyl phosphate proved to be very satisfactory and was used to some extent during the last months of the war.[2]

The Aeronautical Inspection Department's laboratories at Gower Street were equipped largely with a view to dealing not only with the alleged poisonous properties, but with the lack of uniformity of the dopes used early in the war, all of which with the exception of Raftite were made to secret formulæ. It became necessary to call upon dope makers to reveal their formulæ to the inspecting authority. Systematic examination of all the ingredients employed in dope manufacture, as well as a close inspection of the finished product, were successful in preventing the distribution of dope of variable quality. In order that such dopes should not only be correctly made but also correctly applied, each manufacturer was required to publish a "doping scheme" wherein were set forth the conditions and method of application, not only of the dope itself, but also of the dope-covering varnishes associated with the particular scheme dealt with. All such "schemes" were fully tested out at the laboratories before issue.

In the middle of 1917 a great variety of dopes existed, but it was impossible to fix on one standard composition because different fabrics used for special purposes required different treatment.[3] A suggestion was made in September that both acetate and nitro-dopes should be standardised. This seemed premature in view of the impurity of the solvents at that time available, and the inadequate supplies of suitable acetate, that produced by the British Cellulose Company being of very variable quality. To such an extent was this the case that the amount of solvent to effect solution could not be predicted but was a matter for experiment with each batch of acetate. It was also put forward against such a scheme that the result would be to reduce the dope makers to mere mixers, and to eliminate all healthy competition between them. Moreover, if a dope was standardised a breakdown in the production of any of its components would cause a complete hold up in manufacture, whereas with different dopes on the market it would always be possible in case of such a mishap to fall back upon the dope makers unaffected thereby. The standardisation of a series of dopes was, however, recognised as a great advantage from the supply standpoint, and was approved contingently on the supply of adequate and suitable

[1] (Printed) *Weekly Report*, No. 90, VI. (5 May, 1917.)
[2] *Ibid.*, No. 146, VII. (15 June, 1918.)
[3] A.S. 24651/1917.

materials.[1] Early in 1918 the shortage of acetate and solvents had been overcome and in May the department took over the control of dope manufacture and issued standard dope.[2] Contracts were placed to provide 400,000 gallons of standard dope at a flat price, the department issuing all materials.

V. Oxygen.

A small quantity of the oxygen required by the Royal Flying Corps for the first three years of the war was obtained as a by-product of the electrolytic production of hydrogen at the Royal Aircraft Factory, Farnborough, the rest being supplied by a firm who had a practical monopoly for the supply of oxygen.[3] Towards the end of 1917 the requirements for oxygen of the Royal Flying Corps increased very rapidly, and the question of supplying the oxygen in a liquid form was considered and favourably reported on. The question of centralising the control of the supply of oxygen was discussed between the Admiralty and the Ministry of Munitions at the end of 1917,[4] and in December the manufacture and supply was controlled by the Admiralty.[5] It was then arranged that the Oxy-Acetylene Allocation Sub-Committee of the War Priorities Committee, consisting of four representatives of the Admiralty and four of the Ministry of Munitions, should be responsible for the provision of capacity for the manufacture of gaseous oxygen on a commercial scale. In March the same committee undertook to provide capacity for the manufacture of liquid oxygen also, while it was left to the Air Ministry to place contracts and organise the service.[6] Departmental plants were still administered and their products allocated to the department responsible for their establishment, but it was agreed in July that any surplus production should be placed at the disposal of the Oxy-Acetylene Allocation Sub-Committee.[7]

Considerable supplies of oxygen were obtained from the large electrolytic hydrogen-producing plants installed in France by the Department of Aeronautical Supplies,[8] and shortly after the Armistice two portable plants were completed capable of giving ample supplies.[9]

Since 1915 supplies of oxygen cylinders had been provided by the Trench Warfare Supply Department of the Ministry of Munitions as a duty supplementary to the provision of cylinders for cloud gas.[10] The main administrative difficulty had been the development of this class of cylinder in competition with Admiralty requirements for hydrogen bottles. Manufacturing capacity for all steel tubes and bottles was at first allocated by the Admiralty, but the different

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[1] A.S. 27861/1917.
[2] (Printed) *Weekly Report*, No. 146, VII. (15 June, 1918.)
[3] D.M.R.S. 307 A.; HIST. REC./R/1650/3.
[4] HIST. REC./R/1650/3.
[5] For terms of Order see Appendix V.
[6] D.M.R.S. 307 A.
[7] C.R.V./Gen./2479.
[8] D.M.R.S. 307 A.
[9] HIST. REC./H/1960/2, and see Vol. VII, Part III.
[10] See Vol. XI, Part I, pp. 95–96.

Services made their own arrangements for purchase until July, 1918. The Central Hydrogen Department of the Admiralty then undertook to provide and test bottles both for oxygen and hydrogen, requirements having first been considered by the Allocation Sub-committee ; but the special consumers' cylinders were still provided by the department concerned.[1] The ordinary commercial cylinders were found unsuitable for aeronautical work, as being too heavy. There were only two firms capable of producing cylinders which were at all satisfactory.[2] The design of a special cylinder was undertaken by the steel tubing section of the Materials Branch, Department of Aeronautical Supplies, on the request of the Expeditionary Force for bottles which should not exceed 17 lb. in weight. The bottles as designed towards the end of 1917 weighed slightly over 5 lb. and stood a pressure of 50 per cent. above that originally called for and cost half as much to make as the original article.[3] Some of these bottles were provided for the Medical Service in France in July, 1918.[4]

VI. Miscellaneous Materials.

(a) Rubber.

Early in 1916 the attention of the Aeronautical Inspection Department was directed to the necessity for systematic inspection of such aircraft items as petrol-resisting rubber hose, and rubber shock-absorber cord. Of these, petrol-resisting hose claimed first attention, since the material then in use was proving highly unreliable, owing to the well-known effect of petrol and oil on nearly all the rubber mixings of commerce. The tubing had, in addition, to withstand widely varying temperature and pressure. A tentative specification was drawn up, and efforts were made not only to explain to rubber manufacturers exactly what was wanted, but to assist them to produce the desired article. As a consequence of these early efforts the general position was somewhat relieved, but failures on the part of manufacturers to produce a hose of uniform quality gave rise to much anxiety in connection with the ever-increasing aircraft programme. Finally a meeting was called, which was attended by representatives of all the manufacturers who had attempted to make the material. The whole situation was discussed in detail, and the proposition was made that firms should publish their "mixings" and the processes of manufacture in order that any improvements thus disclosed might be universally adopted. It was ultimately agreed that the various manufacturers should disclose this information in confidence to a representative of the Aeronautical Inspection Department and that such information should be used for the general improvement of rubber tubing throughout the country. As a consequence of this, by August, 1917, the production of useless hose was almost entirely avoided,[5] rejections were reduced, and the production raised from an output of 1½ miles per week to a total of seven or eight miles per week.

[1] D.M.R.S. 307 A.
[2] (Printed) *Weekly Report*, No. 108, VI. (8 September, 1917.)
[3] *Ibid.*, No. 118, VIII (17 November, 1917) ; No. 123, VIII A (29 December, 1917).
[4] D.M.R.S. 307 A.
[5] (Printed) *Weekly Report*, No. 105, VI. (18 July, 1917.)

Shock-absorber cord was also much developed as a consequence of action by the Inspection Department. In the early days of the war this material was ordered as "Sandow Exerciser Cord," which in the case of cord of half-inch diameter carried a load at double extension of about 30 lb. As a result of investigations and consultation with the more prominent manufacturers, it was found possible to increase the load carried by cord of this dimension to 130 lb.

(b) LUBRICATING OIL AND PETROL.

Large demands were received in July, 1917, for castor oil, for which contractors would not tender unless they had assurance that the necessary castor seed from India would be forthcoming. Certain types of aero-engines can be lubricated by this oil only, and the consumption of castor oil eventually grew to such an extent as to absorb practically the whole of the world's output of castor seed. The supply of seed was taken over by the Department of Aeronautical Supplies. Representations were made to the India Office, and the Government of India undertook to extend the production of castor seed in that country. At the same time the industry was introduced in America and encouraged in the French Colonies.

Early in 1916 it had become necessary for the Aeronautical Inspection Department to undertake the inspection of aircraft lubricating oils. Considerable difficulty had been experienced owing to the liability of castor oil to freeze, and many forced landings had been due to this cause. The production of a castor oil having a much lower freezing point was therefore essential. Experiments at the Inspection Department's laboratory continued to the middle of 1917, and resulted in the issue of supplies of castor oil which would resist a temperature of 10° C for 16 days, and was safe for use at this temperature up to 21 days. Since April, 1917, no complaint based on the freezing of castor oil has arisen, and no forced landings have been known to be made on this account. Just before the Armistice the volume of lubricating oil inspected by the department amounted to about 750,000 gallons per month.

After the inspection of aircraft lubricating oils had been continued for some four or five months it was decided to undertake the examination of aviation spirit (petrol). An inspection system was organised whereby all supplies distributed from ocean stations were traced to and examined at their destination. No less than 75 per cent. of the available supply of aviation spirit was found at this time to fall short of the requirements of the specification to which it was bought. Confusion in distribution was also taking place and on several occasions heavy transport spirit was delivered to aerodromes for flying purposes. Under the new system of inspection the possibility of wrong delivery was entirely eliminated and the quality of the spirit was rapidly improved, the rejections falling to less than 5 per cent.

(c) Casein Cement and Glue.

Much attention was devoted by the Inspection Department to the adhesive employed to cement the veneers together to form three, five or "multi-ply" boards called for by aircraft designers. Early in 1916 the laboratory organisation had put forward an improved formula for casein cements, but work in connection with plywood specification, as well as the increased use that was being made of casein cements in connection with the manufacture of laminated wood-work in general, necessitated a new and detailed investigation of the whole subject at the beginning of 1918. This resulted in an Air Board specification for casein cements which held good until the end of the war. With the publication of this specification the routine testing of all the ingredients used in the manufacture of casein cement, as well as the testing of the final product, was undertaken by the Inspection Department. Glue also was the subject of early study and close investigation on the part of the Inspection Department. As a material of indefinite composition, the testing of glue provided the department with a number of difficult problems which had to be solved before real progress could be made. Early in 1916 an Aeronautical Inspection Department tensile strength test for glues was introduced and, with other tests devised by the laboratories, enabled the department to classify glues under three heads—Propeller, Class I and Class II grades. Since the way the glue is used is almost as important as the quality of the material itself, the department required every manufacturer of glue to issue a card of instructions concerning its proper use.

CHAPTER VI.

LIGHTER-THAN-AIR CRAFT.

I. Airships.

Work upon airships was begun by the Army in 1902. In 1909 a sub-committee of the Committee of Imperial Defence reported that there were good grounds for believing that rigid airships would be of great value to the Navy for scouting purposes. In 1912, however, this recommendation was reversed, owing to the misfortune of Rigid Airship No. 1 (Mayfly) breaking in half on being returned to her shed after mooring trials, on the ground that the prospects of successful employment were not sufficient to justify the great cost. It was, however, suggested that foreign progress should be watched and the question reopened if important developments occurred. A technical sub-committee reported in July, 1913, that in view of the great progress made abroad, and the many functions, impossible to aeroplanes, that airships could perform, the time had come to adopt a policy of active development, since it appeared that large type airships would be most useful for naval purposes. In the meantime, the Army had been developing small non-rigid airships, and at the end of 1913 all the airships belonging to the military wing were transferred to the naval wing, the latter becoming responsible for the development of all lighter-than-air craft.[1]

At the outbreak of war there were seven airships (all non-rigid). Three, of about 360,000 cubic feet capacity, did considerable patrol work in the Channel during the passage of the British Expeditionary Force.

In March, 1915, owing to the enemy submarine campaign against Allied shipping, instructions were given for the design of a very small non-rigid ship for anti-submarine patrol, of such a nature as to be built rapidly. From this originated the S.S. (submarine scout) type, which carries two or three men and has an endurance of nine hours at a maximum speed of 52 miles per hour. The first S.S. consisted of a B.E.2c fuselage slung to an envelope of a Willows airship. During the summer of 1915 a somewhat larger non-rigid ship of the Astra type was designed and built for more extensive coastal patrol. From this the coastal class was developed, with a full-speed endurance of 12 hours at 52 miles per hour.

An improved type of coastal airship, the Coastal Star, was developed during 1917, to provide greater protection and comfort for the crew, and appeared in 1918. The North Sea type, also non-rigid, was intended for long-distance reconnaissance and convoy work. The first ship of this type carried out her trials in March, 1917, and the endurance, at a maximum speed of 50 miles per hour, was 20 hours.[2]

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[1] Hist. Rec./R/1000/116. [2] *Ibid.*

The design of rigid airships progressed slowly until the German Zeppelin L.33 was brought down in Essex on the night of 23-24 September, 1916, and on this was based the 33 class. The design of the 31 class was based on the German Schutte Lanz type. The building of the earlier types, the No. 9, work upon which had been begun in 1914,[1] and the 23 class had afforded valuable training of skilled labour in duralumin work, but the airships of this class were suited only for training purposes, or local patrol and convoy work.

In August, 1917, the Admiralty laid before the Government a scheme for the development of the larger rigid airships on a large scale.[2] The range of the latest types was approximately 2,000 miles and for naval reconnaissance and oceanic convoy work they offered great advantages over any other type of craft. The Board recommended that a fleet of 16 rigid airships and 70 non-rigids of various types should be kept in commission for war service. This entailed an increase in the number of L.33 class under construction from 5 to 16, the 70 non-rigids being already built or under construction. In spite of the large supplies of steel, aluminium, duralumin, aero-engines, oxygen, hydrogen, and other accessories required for this programme, which coincided with increased demands for similar supplies for heavier-than-air craft,[3] it was approved by the Government in November, 1917, and 16 rigid airships of the L.33 class were ordered. It was decided later that only 11 should be kept in commission, and these were under construction at the time of the Armistice.[4] At that time there were 103 airships in commission, including five rigids. Though at the outbreak of war the British airship service was some 12 years behind the German service, by the end of the war airships of British design were comparable to, if not superior to, any of those used by the enemy.[5]

The design and supply of airships was controlled by the Admiralty throughout the war. Under the Director of Air Services, the Assistant Superintendent of Airships was responsible for supply. It was not until October, 1919, that the provision of airships was taken over by the Air Ministry. The firms employed in building rigid airships were Messrs. Vickers, Armstrong Whitworth, Beardmore and Short. Great difficulties were experienced in production, as there was no such industry in England before the war, and few firms had even attempted the construction of airships. With regard to the S.S.'s, the cars were easily obtainable, being aeroplane fuselages, but the supply of envelopes caused great anxiety. The representatives of three manufacturers of waterproof garments were called together by the Admiralty and were instructed in the art of cutting-out fabric from technical drawings, in the use of which they were totally unfamiliar. However, after a little teaching they retired to their factories and started production immediately.

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[1] *Short History of the Royal Air Force*, p. 268.
[2] Hist. Rec./R/1000/116.
[3] *Ibid.*
[4] *Short History of the Royal Air Force*, p. 269.
[5] *Ibid*, p. 270.

4. Kite Balloons.

Kite balloons were used with great success for reconnaissance and artillery spotting work throughout the war. At the end of 1915 a great advance in their usefulness was made by the practice of towing them from ships. Balloons were of great assistance in the anti-submarine campaign, and were towed from drifters, trawlers and motor launches for reconnaissance purposes when hunting submarines and escorting convoys. Kite balloons were also used for supporting aprons formed of steel cable, used to prevent aircraft raids. For this work a special type of balloon was employed, capable of carrying aprons up to 15,000 feet.

Prior to the war, it had been decided to abandon the use of balloons in warfare owing to the unsatisfactory nature of the spherical type, the only one then in use in this country. It was believed that observation could be more efficiently carried out with aeroplanes and airships. The Germans, however, developed the balloon and produced the Drachen type, which consisted essentially of a sausage-shaped gas-bag with a large air-inflated bag at its rear end, acting as a rudder, preventing rotation, and keeping the balloon head to wind. Fortunately, the Belgians still possessed one of the three Drachen balloons which they had originally had and this was copied, and resulted in the British Drachen-type kite balloon. This, though a great improvement on the spherical type, which would spin round and round and become quite unmanageable in a wind, was not sufficiently stable and the tension on the flying cable was very great. Many experiments on stability were made during 1915-16,[1] and some improvement was made by changing the shape, fitting stabilising fins, and later by the use of wind scoops. During the autumn of 1916 the first French Caquot balloon arrived in this country. It was of streamline shape, and fitted with a large tapered air bag, which passed right round the stern and formed upper and lower fins, instead of terminating as a lower rudder only, as in the Drachen balloon. Eventually, Captain Caquot succeeded in devising an efficient form of air-inflated tail in which three fins of equal size were set at angles of 120 deg., giving complete stability. This, with some modification, was adopted as the pattern for the standard British kite balloon. This type was adapted for towing from ships.[2]

The first winches supplied for the manipulation of kite balloons were driven by steam, and were very cumbersome and ineffective. These winches were improved for naval requirements and finally superseded in land service by a petrol-driven winch, with three or more speeds and reverse capable of hauling down a balloon at 1,200 ft. per minute.[3]

Some means had to be devised for protecting kite balloons from the effect of atmospheric electrical discharges, since it is impracticable to render non-conducting the cable which connects them to earth. To

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[1] *Report of Advisory Committee for Aeronautics*, 1915-1916. Cd. 8315.
[2] *Short History of Royal Air Force, p.* 270, *et seq.*
[3] *Ibid*, p. 272.

overcome this difficulty a form of protecting discharger was evolved. This, when connected with conducting-bands encircling the envelope, and with the wire cable, appreciably reduced the danger of the envelope's being pierced and the gas fired by electric discharges.

Prior to July, 1916, the whole of the kite-balloons and materials for their manufacture required both for Navy and Army Flying Services were purchased and inspected by the Admiralty. In compliance with the wishes of the Army Council, it was arranged in July, 1916, that the War Office should purchase and inspect Army kite balloons as well as materials and accessories, the Admiralty continuing to purchase and inspect those required for the Navy. In order to avoid competition between the two Services, arrangements were made to allocate certain firms to each Department, with the understanding that the output of each firm should be reserved for the Department to which it was allocated.[1] The arrangement was found necessary because balloon design for sea and land work was diverging considerably. Broadly speaking, naval balloons were designed for high wind speeds and great strength, while military design aimed at high altitudes and portability. It therefore seemed that much was to be gained by leaving each Service free to develop design according to its particular requirements, since if the two were amalgamated it was inevitable that the general trend of progress would incline to one or the other ideal and that one Service would consequently be the loser.[2] This arrangement existed up to February, 1917, when the Department of Aeronautical Supplies took over responsibility for Army kite balloons. In April, 1917, the department also undertook supplies for the Navy, and a section consisting of officers from the Kite-Balloon Sections of the Royal Naval Air Service and Royal Flying Corps was formed to deal with these supplies. It was arranged that designs should remain with each Service. It thus came about that kite balloon supply was entirely independent of the Air Board. Programmes were not submitted to the board, and no section of the Technical Department had any responsibility for such research on kite balloons as might arise in the course of manufacture. The arrangements for supply suffered in consequence. The relations of the supply branch with contractors were rendered difficult by intervention on the part of those Service sections which controlled design.[3] Independent arrangements for the production of special or experimental supplies hampered the construction of satisfactory manufacturing programmes to meet the demands of both Services.[4] Owing to lack of staff within the Aeronautical Inspection Department, which was nominally responsible for inspecting all balloons, the actual work of testing was carried out by naval inspecting officers on behalf of the Admiralty and to specifications and designs of their own making. This led to great confusion in the supply branch until September, 1917, when

[1] D.M.R.S. 467 C.
[2] A.S. 17544/1917.
[3] A.S. 33402/1917.
[4] A.S. 26502/1917.

it was agreed that all contracts should be to the inspection of the Chief Inspector, Aeronautical Inspection Department, but that an officer from the Admiralty should be asked to inspect naval kite balloons and winches on his behalf for the time being. Except in urgent cases, instructions to embody modifications were only to be given through the supply branch.[1]

The situation with regard to accessories and materials was also much involved. It has been seen above that it was arranged in August, 1917, that the Admiralty should supply fabric both for Army and Navy kite balloons, and for airships.[2] No authority existed to decide the priority of production between the three requirements, with the result that the needs for kite balloons were inadequately met. The proofing of the fabric was carried out by the Aeronautical Supplies Department for Royal Flying Corps balloons, and by the Admiralty for naval balloons. It was suggested in August by the Admiralty that the proofing for both Services should be done by the Royal Naval Air Service, but the Department of Aeronautical Supplies did not agree to this.[3] The resources of the proofing firms hardly met demands even then, and though efforts were made to obtain fresh capacity, by the end of the year the situation was becoming grave, and, hoping thereby for greater efficiency, the Department of Aeronautical Supplies agreed to hand over full responsibility for proofing to the Admiralty on 31 December, 1917.[4]

It had been decided in April, 1917, that certain gear for kite balloons should be bought by the Admiralty Contracts Department, owing to their more extensive knowledge of the stores, but the decision was not circulated to the Departments concerned, with the result that great confusion arose in dealing with requisitions and placing orders. Naval requisitions for complete balloons and winches passed direct to the Controller of Aeronautical Supplies, and all other naval demands to the Director of Stores, Admiralty, who decided whether orders should be placed through the Admiralty Contracts Department, or passed to the Kite Balloon Section of the Department of Aeronautical Supplies for action through the Aeronautical Contracts Branch. All Army requisitions were passed to the Controller of Aeronautical Supplies, and it was left to the Kite Balloon Section to decide which contracts branch should be asked to take action.[5]

In September, 1917, the responsibility for the purchase of gear and materials was distributed somewhat as follows :—

Purchased by the Admiralty on behalf of both Services :—(1) cotton fabric, (2) hydrogen compressors and spares, (3) hydrogen tubes, (4) wire for cables, (5) silk for parachutes, (6) ferro-silicon.

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[1] A.S. 17544/1917.
[2] See above, p. 131.
[3] A.S. 17544/1917; (Printed) *Weekly Report*, No. 108, VI. (8 September, 1917.)
[4] (Printed) *Weekly Report*, No. 118, VIII. (17 November, 1917.)
[5] A.S. 17544/1917.

Purchased by the Admiralty for the Royal Naval Air Service, and by the Ministry of Munitions for the Royal Flying Corps:—(1) silicol plant, (2) caustic soda, (3) blowers, (4) winches for use on ships, (5) proofing of fabric, (6) parachutes.

Supplied by the Ministry of Munitions for both Services:—(1) complete balloons, (2) cordage, (3) cables, (4) portable sheds,[1] (5) winches.

It was suggested at a conference held in September that this distribution of authority should be confirmed, with two exceptions—ferro-silicon and parachutes—for which it was proposed that the Ministry should in future be responsible.[2] The responsibility for the supply of silicol was definitely allotted to the Steel Department of the Ministry of Munitions.[3] These decisions were not, however, confirmed in their entirety, and though the position improved it still remained unsatisfactory.

In June, 1917, there had been very urgent demands for increased production of naval kite balloons, and contracts were placed for seven balloons a week for this purpose.[4] The naval requirements increased throughout the year until, in December, the demand was for a minimum of 23 balloons per week.[5] At the beginning of 1918 kite balloons were rapidly increasing in importance, and a large number was required in connection with the defence of London scheme. The total demand in February was for 85 balloons per week. This was being satisfactorily met as far as army balloons were concerned, the proofed fabric having been controlled up till the beginning of the year by the Department of Aeronautical Supplies, but there was a serious shortage in the production of Navy balloons, owing to inadequate supplies of proofed fabric from the Admiralty. Only sufficient fabric was being produced for eight balloons weekly, whereas demands existed for 30 per week.

The whole question of the supply and inspection of balloons and fabric, accessories and hydrogen plant was again referred to a conference of the Departments concerned in February, 1918, and, as appears above, the War Office undertook the supply and proofing of fabric, while the supply of balloons remained with the Ministry of Munitions. The question of winches was not at once settled, as different types were in use by the two Services. In April it was decided that the Department of Aircraft Production should buy these for both Services.[6] It was found in May, 1918, that the situation with regard to the future supplies of fabric was particularly serious. Practically no provision had been made for increasing the amount of proofing to meet the new demands, and on some specifications a complete shut down seemed inevitable

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[1] The supply of portable sheds (canvas) for the Royal Naval Air Service had been taken over, at the request of the Admiralty, in August (D.M.R.S. 467 C.).

[2] A.S. 17544/1917.

[3] A.S. 26502/1917.

[4] (Printed) *Weekly Report*, No. 96, VI. (16 June, 1917.)

[5] A.S. 26502/1917.

[6] (Printed) *Weekly Report*, No. 138, VII. (20 April, 1918.)

unless substitutes could be found.[1] However, the War Office, working in conjunction with the Department of Aircraft Production, organised the proofing industry in such a manner as to make adequate provision for all demands.[2]

By a decision of the conference of February, 1918, hydrogen and silicol plant became the responsibility of the Admiralty in August, 1917, a change which had already been contemplated.[3] A Central Hydrogen Department was set up at the Admiralty for the design, purchase and erection of hydrogen plant of all descriptions, the supply of all materials for running the plant, and the control of its working. The operation of overseas plant, such as the hydrogen-producing plant which had been installed in France, was to remain with the Service concerned. It was also decided that the existing Oxygen and Calcium Carbide Allocation Committee should ascertain requirements and allocate supplies of hydrogen between the Services, and decide on general policy, for instance in regard to extensions. In addition the Central Department became responsible for the supply and testing of bottles, both for hydrogen and oxygen.[4]

At the beginning of 1917 there were only three firms producing kite balloons, and it was necessary to organise and equip fresh factories, including a national factory. This policy of broadening the basis of supply resulted at the time of the Armistice in the existence of eleven factories capable of producing the Caquot type, and five factories producing the Nurse or Feeder type.[5] In the organisation of new factories the policy of the Department was to send to the works one or two skilled production officers and three or four air mechanics. In this way contractors were able to educate a nucleus staff which could be expanded as necessity arose. As a result of this policy no case arose in which any difficulties were experienced with regard to the rejection of goods owing to faulty workmanship.[6]

In June, 1917, serious complaints were received from the Expeditionary Force with regard to the porosity of balloons, and it was stated that those sent out would not hold gas and it was impossible to maintain altitude. At the time this complaint was received there was no Technical Section in connection with the supply of Army type balloons, and the necessary investigations were therefore undertaken by the supply section.[7] Research work was also undertaken on the general question of proofed fabric permeabilities and balloon-seam construction. With a view to full investigation, arrangements were made for the two principal proofers to proceed with a representative of the section on a tour of inspection of the French technical sections and French factories, and as a result certain satisfactory modifications were made in the proofing specification.[8] To cope with the difficulty of seam construction a special

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[1] (Printed) *Weekly Report*, No. 141, VII. (11 May, 1918.)
[2] HIST. REC./H/1960/2.
[3] A.S. 17544/1917.
[4] See above, p. 144.
[5] HIST. REC./H/1960/2.
[6] *Ibid.*
[7] A.S. 17096/1917.
[8] *Ibid.*

rubber-testing instrument was devised and valuable data collected, which resulted finally in the amendment of the specification for material for the construction of balloon seams.[1]

III. Parachutes.

With the exception of parachutes for airships, which were supplied by the Admiralty, the Department of Aircraft Production was responsible after September, 1917, for all parachutes.

All the earlier parachutes were of Messrs. Spencer's type, and this firm was able to satisfy all demands. It was never necessary to make any modifications in this type, and during the war it was the only one in use with kite balloons.

In May, 1918, demands were received for a large supply of parachutes for aeroplane purposes. "Guardian Angel" parachutes, a few of which had been supplied at intervals to the British and Allied Governments, were found to be the only type capable of being launched from an aeroplane. In November, 1918, man-carrying parachutes were not on a production basis, as certain improvements were still being carried out, but adequate facilities had been arranged and five firms had been trained in the work.

IV. Pilot Balloons.

These were small rubber balloons for making observations of the upper air, and were found useful for finding the speed and course of the wind before machines set off on a bombing expedition, as by this means the bomb-sights could be adjusted before the machines left the ground. In June, 1918, it became necessary to increase the output of these balloons, which were also used by the Meteorological Office, Admiralty, and in August the Department of Aircraft Production undertook the whole supply. Very few firms made this class of balloon, and as manufacture was troublesome and quality difficult to maintain, it was not nearly so profitable as toy balloons and rubber toys, and some pressure had to be brought on contractors to provide the necessary supplies.[2]

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[1] Hist. Rec./H/1960/2.

[2] D.M.R.S. 467 C.

CHAPTER VII.

SOME PROBLEMS AND ACHIEVEMENTS.

I. Standardisation.

(*a*) THE DIFFICULTIES OF STANDARDISATION.

The technical difficulties involved in the production of aircraft and aero-engines in mass were very great. The supply of trained engineers was from the first totally inadequate to meet the demands made upon the profession for designers, draughtsmen, inspectors and production officers, so that difficulties which would have been formidable even had there been adequate engineering talent to deal with them became almost overwhelming when complicated by errors due to inefficient treatment. The main difficulty throughout was the experimental nature of the supplies concerned. Under ordinary conditions bulk production would not be attempted until the store had passed the experimental stage and become standardised in every particular. Before the war, exhaustive experiments were carried out at the Royal Aircraft Factory and both machine and engine were approved for service before contracts were placed with the trade by the War Department. The Navy depended on "proprietary" types, for the design and drawings of which a particular firm was responsible, and much progress in design had thus been encouraged in the industry itself. Directly war broke out it was found that the Royal Aircraft Factory and proprietary firms were quite unable to cope with the preliminary work required, and the trade was called upon to undertake manufacture from incomplete and erroneous drawings or even without drawings, while standardisation and elimination of faults had to be effected as manufacture proceeded. The adoption of any type, either of aircraft or engine, was in the nature of a gamble, as its merits could not be assessed without actual air experience, and since this took months to gain, selection had to be made and production started on any machine which appeared to offer a promise of satisfactory performance. This led to a continuous stream of modifications affecting every minute part of the machine and entailing endless scrapping and delay. The effect upon manufacturers was disheartening, and constant alteration in prices involved contracts and finance departments, while the drawing offices, inadequately staffed to meet even the normal demand for original drawings, were utterly unable to cope with the stream of alterations required. The complex nature of the industry and the large number of sub-contractors involved in the production of aircraft added to the difficulty, since their resources and works organisation were often inadequate to carry out changes as quickly as was possible at the main contractors' works.

The only possible way of dealing effectively with the difficulty would have been to standardise types and components, and this during the first three years of the war was impracticable and from many points of view undesirable. From the manufacturing point of view alone, some variation in type was desirable in order to make use of a number of small firms whose factories were specially designed for one class of work and could not easily have been adapted to any other purpose. The Air Services were constantly being required to undertake fresh duties for which special types of machine were needed, while demand for improved performance was constant. Machines became obsolete very quickly, owing sometimes to the rapidity with which better types were evolved at home, and sometimes to their being outclassed by enemy craft of similar type. A change in military policy demanded in the interests of efficiency might involve the scrapping of an aeroplane type even before it reached the production stage. A case of this occurred at the end of 1917, when a complete change which was made in methods of training involved wholesale cancellation of contracts for D.H.6 machines. The early system consisted of preliminary practice on a machine easy to manipulate, on which the pupil learnt to fly by himself before being taken to higher instruction and aerobatics. For this purpose the D.H.6 was designed to replace the Maurice Farman, which had been used in the early days of the war, but was an expensive machine both in mechanics and materials. A large order for D.H.6 was placed in the summer of 1917 to cover the training programme for 1918, but in the autumn of 1917 the principle of training was altered entirely, and the pupil before being allowed to fly solo was put through a whole course of aerobatics and landings with dual control and then sent to fly on advanced training machines. D.H.6 was quite unsuited for advanced flying and immediately became redundant, but the new method of training produced more efficient pilots in a shorter time and reduced the risk of accidents.[1] This change also entailed scrapping Renault engines and turning firms over to the Hispano-Suiza Viper, a far more serious matter even than the alteration in aeroplane type, since the engine contractor who had spent twelve months preparing tools for the production of Renault parts would get no production off these tools, and would have to make others suitable for the Viper engine before getting any output. This entailed compensation and long delay in production, but cases of this nature could not be avoided.

Differences in the conditions to be fulfilled by naval and military machines also tended towards a multiplication of types. The distinct consideration of designs for the two Services led to a development of numerous special fittings and entailed the provision of spares peculiar to certain machines only. Some centralisation of authority appeared essential to the effective consideration of so complex a problem as the standardisation of machines. The Ministry of Munitions, upon taking control of supply, made an effort to deal with this need, and was aided in this respect by the concurrent demand for production on a greatly increased scale. It was, however, just at this period that the separation between the technical and supply branches took place,[2]

[1] A.S. 12776/1918.

[2] See above. p. 64.

thus for a time making co-operation difficult when the need for it was greatest. Technical officers, free from the worries of production problems, were naturally mainly concerned to produce the most perfect types possible, and it was difficult for them to realise that the attainment of high ideals in this respect might entail a very poor output. On the other hand, supply officers, who were only too familiar with the difficulties incident to change of design, were liable to under-estimate the urgency of those changes.

It will be seen that the problem was a triple one, standardisation of types, standardisation of components and materials for all types, and the attainment of interchangeability of parts in the same type of machine. The third problem was primarily one of mathematics, the second could not safely be dealt with until extensive experience had been gained, and no comprehensive solution was attempted until the beginning of 1918. The first called for immediate and drastic action.

(*b*) STANDARDISATION OF TYPES.

In January, 1917, the Army was using 48 different types of aeroplane belonging to seven different categories (fighters, corps reconnaissance, fighter reconnaissance, medium range bombing, long range bombing, training and experimental). The Navy was using 43 types, but of these 15 were the same as those used by the Army, giving as the net number of types, 76.[1] The number of seaplane types was 32. Thirty types of engine were used by the Army and 39 by the Navy, the net number of different types being 57.[2] It was apparent that mass production could not be obtained on these lines, and a drastic reduction in the number of types was effected directly the Controller of Aeronautical Supplies took over supply. The policy adopted was to obtain as many as possible of the types most readily procurable, so that in the future a general standardisation policy could be undertaken without seriously crippling the growth of establishment. By 1 March, 1917, engine types had been reduced to 33, while the main types appearing on the new programme were about 20 in number. Aeroplane types were 39, about 30 of which appeared in quantities in the new programme. Seaplane types had been reduced to 16.[3] Experimental manufacture of aeroplanes was controlled by an order of the Ministry issued in March, 1917, no one being allowed to proceed with experimental manufacture without a permit. This instruction was extended to aero-engines a year later.[4] By September, 1917, the Supply Department was working on an engine programme of approximately 13 types and on an aeroplane programme of 14 types,[5] though many other types were still in production and requirements

[1] This number has also been given as 51. The discrepancy in the figures is probably due to a difference in opinion as to what constituted a difference in type.

[2] D.M.R.S. 467.

[3] D.M.R.S. 467.

[4] The Aeroplanes (Experimental Manufacture) Order, 1917. The Aero-Engine (Experimental Construction) Order, 1918.

[5] HIST. REC./R/1960/5.

changed with such rapidity that absolute figures were difficult to give at any time. It had, however, become much more difficult for the Technical Department to secure the admission of a new type, either of aeroplane or engine, to the constructional programme, since the outstanding experience of the past six months had been the difficulty and delay associated with the process of putting a new type into construction, particularly in the case of an engine when it had been chosen before being thoroughly tested. The B.H.P. engine ran on the test bench in June, 1916, but was hardly in bulk production by September, 1917. The oldest engines were found to be the most reliable because they had been under the process of elimination of troubles for so long.[1] By 1 March, 1918, the number of engine types was 25, to be reduced by the end of the year to 12, aeroplane types were 18, to be reduced to 12, and seaplane types 12, to be reduced to six.

Lord Rothermere, on taking office as Secretary of State for the Royal Air Force in January, 1918, took up the matter of further standardisation of aeroplane and engine types and of their armament and equipment. He contended that since the gross weight per horse-power was now accepted as the criterion of the performance of a machine, little more was to be expected in the way of performance until either some radical change in the construction of the machine, or the reduction of the weight per horse-power of the power unit was achieved. Since neither of these achievements was in sight, he thought the time had arrived for a comprehensive policy of standardisation, both for aeroplanes and engines, reliance for improvement in performance being placed on systematic development which would normally take place. Nineteen different designs of machines were then in constant use. There were four different designs of rotary engines of similar weight and horse-power, and diversity of types was as great in stationary engines. The same applied to armament and fittings. A process of elimination seemed desirable. The effect of concentration on a few types in the reduction of difficulties then encountered with regard to drawing office facilities, quick execution of modifications, inspection, acceptance and test, was readily to be seen. The transfer of the technical branch to the Department of Aircraft Production rendered such a policy much easier, in giving supply officers a stronger influence over the technical staff, and the danger of cramping the initiative of designers could be met by providing a generous experimental system. The policy of elimination was adopted as far as circumstances of production permitted. It could not be carried out on the wholesale scale advocated by Lord Rothermere, as it was impossible to upset existing contracts and risk curtailment of supplies merely to get simplification of type, and only new orders could be planned on these new lines. As has been seen above, the breakdown in the supply of certain engines prevented the complete adoption of the policy, since obsolete types had to be kept in production, and in September, 1918, there were 19 engine, 22 aeroplane, and 12 seaplane types still in production, while the number of engines to be adopted for the service in the future was 8.[2]

[1] Hist. Rec./R/1960/5. [2] Hist. Rec./R./1964/3.

(c) STANDARDISATION OF MATERIALS AND COMPONENTS.

The question of standardisation of aircraft materials had an important bearing on production. The multiplicity of designs and sizes of such parts as steel tubes, rivets and valves involved innumerable small orders which seriously hindered output and absorbed much skilled labour.[1] The Admiralty had standardised steel tubes in February, 1916, and these standards, with some additions, were adopted for both services in April, 1917. Screw threads provided another instance where standardisation was much to be desired, since gauges were required for every type of screw, so that a variety of types of screw involved a corresponding variety of gauges. The threads in use at the end of 1917 in existing engine designs were chiefly metric, Whitworth and British Standard Fine, but there was a variation in pitches which brought the total of threads in use to about 800.[2] It had been laid down in May, 1917, that all new designs of engines should incorporate B.S.F. and B.A. threads for all diameters up to 1 in. Beyond that no standard had been arranged, as it was thought that B.S.F. threads were too coarse for the larger sizes.

The general question of standardisation of materials was taken up seriously for the first time in January, 1918, when experience gained and the large measure of control then extended over materials seemed to warrant the preparation of a comprehensive scheme, without incurring any risks of hampering progress in design. The British Engineering Standards Committee undertook the work of standardisation for the Department of Aircraft Production, and a committee, under the chairmanship of Sir Henry Fowler, K.B.E., Assistant Director-General of Aircraft Production, with some thirty-five sub-committees and panels, was soon at work. Permanent national committees were instituted in the Allied countries to maintain continuity of action and co-ordination, the Engineering Standards Committee for the time being acting as the distributing centre of the permanent international organisation. The work of standardisation covered nomenclature, timber, glue and casein cements, airscrew hubs and fixing, water and fuel systems, wireless, electrical parts, instruments, ball and roller bearings, sparking plugs, magnetos, wheels and tyres, structural and exhaust-pipe tubing, rigging and components, rubber, dopes and fabrics, aircraft steels, copper alloys, cast-iron, installation of apparatus, lubricating oil and petrol.[3] In the case of turnbuckles it was decided in January that the time had not arrived for standardising any particular type.[4] The specifications for copper alloys presented considerable difficulties, and it was found difficult to persuade manufacturers to lay aside their own private specialities and to accept the alloy specifications.[5] In the case of carburetters no finality of design was reached during the war. This was caused to a great extent by the

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[1] A.S. 6272/18.
[2] M.C. 347.
[3] (Printed) *Weekly Report*, No. 136, VII. (6 April, 1918.)
[4] *Ibid.*, No. 124, VIII A. (5 January, 1918.)
[5] *Ibid.*, No. 139, VII. (27 April, 1918.)

ever-increasing ceilings obtained.[1] The work of the panels continued until November and considerable progress was made. An inter-allied conference on the subject was held in October, and a number of advisory committees were appointed to make detailed proposals on subjects on which international agreement was desirable.[2] When some degree of standardisation had been reached both as to types and parts, it became possible to construct machinery for the automatic shaping of spars, struts, and numerous other parts of the machines, work which had formerly been done by hand by highly skilled workers, and in this way the problem of skilled labour was partially solved.

The question of standardisation of the parts of French engines which were being manufactured both in France and England was of special importance, since, once standardisation had been obtained, spare parts for all French engines could be made in England, and endless trouble in procuring various sorts of small spares from France could be eliminated. The matter was taken up early in 1917, but in August was still unsettled.[3]

(*d*) The Problem of Interchangeability.[4]

Before recording the work done by the Aeronautical Inspection Department in connection with this subject, it would be well to explain what interchangeability means and why it is imperative to secure it when mass production is attempted. Interchangeability is secured between components such as a wing and a fuselage, for the same type of aircraft, when any wing can be attached to any fuselage without the necessity for alteration. Before interchangeable components were made it was necessary to perform extra work upon them in order to make them assemble.

Soon after the war began, the question of supplying to the Service aeroplane components which could be assembled to machines without any fitting received a little attention at the Royal Aircraft Factory, but the matter was undoubtedly neglected by other designers of aeroplanes. Of the machines then being supplied by the Military Aeronautics Department by far the larger proportion consisted of designs originated at the Royal Aircraft Factory, where some efforts were being made to obtain interchangeable components, by stating on the drawings the limits of error on leading dimensions, and by the issue of gauges to contractors. These efforts were only partially successful because they were not based upon a fundamental principle, and the gauges available were insufficient to meet the demands.

The proprietary machines which were being constructed at this period were produced by the designing firms in their own factories, so that interchangeability as far as they were concerned was a local matter only and should have been assured without much difficulty.

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[1] A.S. 36328/1918.
[2] *Ibid.*, No. 166, VII. (2 November, 1918.)
[3] (Printed) *Weekly Report, passim.* A.S. 24690/1917.
[4] Based upon Hist. Rec./H/1960/2.

In those days, however, no clearances were allowed between the fitting members of components, with the result that even when produced correctly to the drawings, such components could not be assembled in the field owing to expansion and other deformation in the timber.

Early in 1917 the question of interchangeability was brought to the fore because of the large contracts for machines of private design that were then placed. In February, 1917, it was decided that the Aeronautical Inspection Department should be responsible for accepting components guaranteed to be interchangeable, and in March a special sub-section was formed to deal with the subject. The existing conditions were extremely unfavourable. Machines of new types were being rushed into production without due attention being given to jig and gauge making. Ignorance of the real meaning of interchangeability and methods of securing it was widespread, and there was a serious dearth of measuring instruments suitable for checking position of hinges, etc., in the absence of gauges or templates. Further, the situation was rendered most complex through the policy of placing contracts for one type of machine with several contractors.

A recommendation made by the Technical Department in April, 1917, that, in order to save floor space and large staffs of erectors, only one machine in ten, after the first ten, should be erected at the contractors' works, was premature, on account of the incomplete degree of interchangeability attained at that time. The Inspection Department suggested that a compromise might be made between complete erection and no attempt at assembly, by requiring the contractors in the case of fuselage machines to erect the fuselage with under-carriage, top centre section and bottom centre section (if any), tail plane, fin, rudder, and elevators being fitted, and all controls connected up, except those to the wing flaps. The only dismantling necessary to pack the machine would be the removal of the tail plane, rudder and elevators. In the same way, in a pusher machine, the nacelle with under-carriage and lower centre section, if any, should be completely erected, while the tail booms should be erected in a jig as a separate unit and the tail plane, rudder, elevators and fin assembled thereto. In this case again, the only dismantling necessary would be that of the tail plane, rudder, fins and elevator. It was thought that this degree of assembly would not involve more floor space than would a complicated system of jigging and the suggestion was guided by the consideration of the much greater difficulty of designing jigs to ensure the interchangeability of each and every component as compared with the simplicity of the jigs which would suffice to secure interchangeability as suggested. The existing stage of development of jigs seemed to involve the risk of accepting machines that would not assemble, and in any case the facilities for performing the work of erection speedily and accurately must have been superior at a well-equipped factory to any which could exist at a mere aerodrome shed, the accommodation at an acceptance park.[1] Finally, discretionary power was left with the Director of Inspection as to complete erection.

[1] A.S. 23280/1917.

Before describing the methods adopted for dispelling the widespread ignorance which existed on the subject of interchangeability, a few examples are given below of the erroneous ideas current on the subject :—

(*a*) That clearances are unnecessary because components are made to " dead " correct dimensions by means of jigs.

(*b*) That it is not necessary to calculate " limits of error," and that if limits, which have been set in an arbitrary manner, are adhered to by all concerned, interchangeable components will result.

(*c*) That it is possible to ensure interchangeability by using as a gauge for a component a mating component constructed to " dead " correct measurements.

It was obvious that no headway was possible unless a start was made upon correct fundamental principles. To allow for changing climatic conditions and inaccuracy of workmanship limits of error must be allowed upon the important dimensions and clearly stated against such dimensions on the drawings, whilst to provide for changes in condition of the material employed and to facilitate assembly, " clearances " are needed between the details connecting one component to another. Mathematical investigation was made into the subject and data sheets were issued for educational purposes among Aeronautical Inspection Department staff and contractors.

It must be understood that the question of interchangeability should be taken into consideration while a machine is being designed, in order that the drawings to be used for production purposes shall embody all the essential limits of error which can be allowed. At the time when the Aeronautical Inspection Department first approached this subject, however, about six different types of machines of private design were about to go into production, although the drawings, without the necessary limits, were already in the hands of the contractors. The extremely difficult situation thus created had to be met by means of careful investigation and compromise. It meant that different contractors working on the same type of machine, and isolated from one another, had to be brought into line by slight readjustments of their methods in order that even a partial degree of interchangeability could be secured. The results, arrived at in such a way as to cause the least possible inconvenience to the contractors, were recorded in the form of a special sheet, known as an interchangeability sheet for each machine. In this sheet were shown diagrammatically the main components of the machine and any special details such as hinges, etc., which govern interchangeability. Only those dimensions upon which special limits of error were necessary in order to secure interchangeability were shown, all other dimensions being obtained from the detail drawings.

After the adoption of these interchangeability sheets, it was considered desirable to provide some form of master gauge for the purpose of checking workshop gauges produced by a contractor, and here the difficulty of supplying the ordinary type of master gauge

(owing to the shortage of skilled labour) was experienced. To overcome this difficulty a special form of master gauge was developed, and ultimately manufactured and distributed among Aeronautical Inspection staffs at resident stations. Owing to the fact that it was possible to manufacture these gauges by repetition methods, considerable use was made of them, both by contractors in the construction of their workshop gauges, and by the examining staff for periodically checking these. The drawings of master gauges for any one machine were grouped together on one sheet. These drawings were used in the production of master gauges, and were also available for the contractors, who could utilise the dimensions given thereon in the design of workshop gauges without having to make the calculations necessary to arrive at such figures.

Designs for workshop gauges were not undertaken by the Inspection Department at first, but technical advice and assistance were available, and were frequently given to contractors in difficulties. If it had not been for the scarcity of staff in the Inspection Department, much more could have been done in helping contractors with the design of their workshop gauges and jigs. Towards the end of 1917 the number of contractors who had no gauge-designing or manufacturing facilities became so great that it was decided to modify the contract conditions, with the object of rendering further assistance. Drastic steps were taken to augment the staff, in order to cope with the designing of workshop gauges of various types. This centralisation of the work proved to be an advantage, in that it was possible to work upon a "standardised parts" policy. In a few weeks designs had been prepared for a large number of standard details, such as lengths of "trued-up" channel steel, cast-iron blocks, standard pins, standard bushes, and other gauge fittings capable of being produced in quantities, and held in stock for special machining and assembly. The workshop gauges for any particular machine were designed as necessary, all possible use being made of these standard fittings.

In addition to the saving of labour in making replacements in the field, the attainment of interchangeability tends to simplify production. If it is certain that all wings and fuselages comply with instructions contained in the interchangeability sheet, it is unnecessary to erect the wings to the fuselage, if the machine has to be despatched from the works in a disassembled condition, and in October, 1917, it was possible to build upon the work already accomplished by introducing a scheme whereby such superfluous erection of wings could be dispensed with, as soon as the Aeronautical Inspection Department was satisfied that certain conditions had been fulfilled. These conditions were :—

(1) The production of components within the specified limits of error.
(2) The provision of a gauge for checking all the important features of the wings.
(3) The provision of a T-square gauge for assembly to a fuselage to check that the wing attachments were accurately positioned.

The majority of the contractors welcomed the scheme, and equipped themselves to adopt it, with the result that the floor space and labour thus released were utilised for other work. In this way a considerable increase in production was effected. In January, 1918, arrangements were completed for the creation of small committees charged with the responsibility of preparing interchangeability sheets and designs for workshop gauges for any machine of which production in quantity was anticipated. The drawings were to be made by the designer's staff. These committees consisted of the designer of the machine or his representative, a representative of the Controller of the Technical Department, and of the Chief Inspector of Aeroplanes, the two latter being resident at the premises of the designer, until their responsibilities were discharged. By this means the question of interchangeability was considered when the detail drawings were being prepared, thus avoiding the inevitable confusion which existed when the Inspection Department first grappled with the problem.

With the advent of the large bombing machines, towards the end of 1917, fresh difficulties were encountered, owing to the size of many of the components. The larger the components to be dealt with in the field, the greater the necessity for easy assembly; hence the need for special steps to secure interchangeable components. In one instance an attempt was made to use large gauges, the weights of which were so great that it was necessary to offer up the components to the gauges instead of the gauges to the components. Such methods involved extra handling of components, and undoubtedly interfered with the best shop practice. It was therefore decided to abandon the checking of large components by means of gauges, and to ensure interchangeability by the use of specially-constructed manufacturing jigs, which could be depended upon in every way.

In May, 1918, it was possible to collect the information obtained by calculation and practical experience, and issue it in the form of a data chart applicable to any type of machine. All the limits of error on dimensions affecting interchangeability of the main components, which by experience were found to be most desirable, were shown on the chart. Large clearances were aimed at wherever possible to simplify manufacture and facilitate the work of the Royal Air Force in the field, where rapid assembly must be accomplished under any atmospheric conditions. In the beginning of 1918 the volume of work on this subject was so great, and increasing with such rapidity, that it was decided to appoint an interchangeability specialist in each district in order to decentralise the work. Conferences of these specialists, held periodically at headquarters, together with their weekly reports, resulted in considerable progress along the lines already laid down, and in amendments of policy to meet the varying conditions encountered at the different works.

The supply of the necessary gauges for the manufacture of aircraft, engines, and accessories was always a difficult matter. The supply of all gauges was in the hands of the Gauge Department of the Ministry of Munitions,[1] but towards the end of 1917 supply fell considerably

[1] Vol. VIII, Part III, Chap. I.

below demands, and special steps to improve the situation became necessary. The peculiar difficulties experienced by the Gauge Department in obtaining increased supplies for aeronautical work were chiefly due to the large number of different types required, and difficulties in connection with the metric thread. It was impossible to alter the metric thread, as it was used in France, and interchangeability between parts of French and English manufacture was necessary. Little could be done in reducing the number of types of thread in aero-engines, but some improvement was possible in the screws used in aeroplane work. A list of existing threads was drawn up, and designers were informed which types it was desirable to use. A liaison officer was appointed between the Department of Aircraft Production and the Gauge Department on 5 January, 1918, to keep the latter department informed as to the peculiar needs of aircraft work and the priority of the different types of gauge, and a sub-section of the Machine Tool Section of the Department of Aircraft Production, was formed to collaborate with the Gauge Department, and to keep in touch with the requirements of firms for jigs and gauges.[1] A scheme was initiated whereby gauges could be made on production machinery to eliminate the difficulty of obtaining skilled labour, but this did not come into operation before the Armistice.

II. Alterations during Manufacture.

(a) MODIFICATIONS.

While these efforts were being made to secure standardisation, it was necessary to devise some means of dealing with the innumerable modifications which were still necessary. As regards aeroplanes and seaplanes, immediate steps were taken to classify the modifications according to their urgency and establish a definite procedure to guide supply officers. Class I included vital modifications which had to be introduced for safety's sake, regardless of delay in delivery and expense, however occasioned. The Controller of the Technical Department informed the Controller of Aeronautical Supplies of such modifications, and the latter thereupon held up all deliveries until the alteration was incorporated. Class II modifications were essential ones and had to be incorporated with as little delay as possible without interfering with the rate of delivery, but expense was not to be considered. Representatives of the Technical and Supply Departments consulted as to the period of grace which should be allowed to individual manufacturers before alterations of this type became Class I modifications for immediate adoption. Class III included desirable modifications, corrections of errors in drawing and additional information. Changes thus classified had to be introduced in all parts under manufacture and in such machines as would not be delayed thereby, without occasioning any expense either by scrapping or dismantling of parts. The incorporation of these modifications was left to the discretion of supply officers.[2] Small committees were

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[1] M.C. 347.

[2] A.S. 30638/1917.

formed for dealing with alterations to aeroplanes and seaplanes, consisting of representatives of the Supply and Technical Departments and the Services.[1]

Engine modifications were not dealt with in this way, and the difficulties in production arising from constant alterations in design were contributing factors towards the very unsatisfactory state of engine supply in the summer of 1918. The Engine Sub-Committee, at that time considering the engine problem, recommended that modifications should, as far as possible, be issued in batches, and that an Engine Modifications Committee, on the same lines as the existing Aeroplane and Seaplane Modifications Committees, should at once be set up. With regard to accessories, there seemed to be insufficient co-operation between the various sections dealing with accessories and those dealing with the aeroplane and engine proper. Modifications were made to accessories without due consideration of the modifications which they involved to the machine. An Installation Modifications Committee was therefore set up to deal with all such matters. The necessity for keeping these committees as small as possible was obvious, and they were limited to representatives of the Technical, Supply and Inspection Departments, though a suggestion was made that the Contracts Branch should be represented owing to the effect of modifications on price.

Examples of the lengthy delays due to the incorporation of modifications were of weekly occurrence during 1917. Modifications of apparently unimportant parts often caused as much delay as basic alterations in design. It was estimated that alterations in the centre section bracing lugs of the Sopwith Triplane, a Class II modification, would cause at least a fortnight's delay, while a new undercarriage proposed in June for R.E.8, also Class II, would entail both considerable delay and scrapping.[2] An alteration in the reduction gear between engine crankshaft and airscrew in the Arab engine, together with other small modifications, produced delay estimated at six weeks.[3] Again, alterations in the type of some accessory would often involve alterations in others, or even in the main structure of the aeroplane. A suggestion that the engines in B.E.12 machines should be fitted with Brown and Barlow carburetters entailed extensive alterations in the fuselage of the machine.[4] The mounting of gunsight brackets in D.H.5 involved the difficult operation of drilling the glass wind screen,[5] while the substitution of a 20 in. for a 23 in. gun ring in F.2A seaplanes involved structural alterations to the hull.[6]

The classification of modifications was not at once adopted in the case of kite balloons. In October, 1917, the changes in design were so frequent that the Supply Department suggested that lists of alterations should be forwarded to the contractors monthly instead

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[1] HIST. REC./R/1964/3.
[2] (Printed) *Weekly Report*, No. 97, VI. (23 June, 1917.)
[3] *Ibid.* 107, VI. (1 September, 1917.)
[4] *Ibid.* 97, VI. (23 June, 1917.)
[5] *Ibid.* 100, VI. (14 July, 1917.)
[6] *Ibid.* 110, VI. (22 September, 1917.)

of in a continuous stream. The constant changes then taking place were due to the fact that, until about that time, manufacturers of balloons and balloon material were given a more or less free hand to supply what they thought fit, and attempts were then being made to standardise supplies and bring all manufacturers into line. The plan of gathering modifications into monthly lists was adopted for the time being, but from April, 1918, the alterations were classified and incorporated as in the case of other aircraft supplies.[1]

(*b*) CONCESSIONS.

Changes in specification were made from time to time to assist production. The original specification for turnbuckles demanded 55 ton tensile nickel chrome steel, but the design was altered so that they could be manufactured from a more easily worked material of 35 ton tensile steel. A similar alteration in specification was made for pins, enabling them to be produced in a metal of which there were ample supplies. In the summer of 1917 great difficulty was experienced in obtaining suitable wire for cable-making, owing to the stringency of the torsion test demanded. The depreciation in the quality of rods then procurable made it impossible to meet the test and a reduction of its severity was agreed to.[2] The substitution of a four-strand cable for the seven-strand in 5 and 15 cwt. sizes had the effect of doubling the output. Early in 1918 the specification for steel in exhaust valves for certain engines was changed to kinds of steel which were easier to obtain, and in March all steel specifications were reviewed with the object of changing from alloy to carbon steel where possible.

Owing to the constantly increasing demand for output, concessions on manufactured parts became at times unavoidable. Some parts, while fulfilling the requirements of safety, did not present the usual degree of interchangeability, finish, or reliability, and these, if accepted, were stamped "P.P," indicating that they had been passed for production. The acceptance of such parts was in certain cases made the basis of a reduction in contract price. It was sometimes cited by the critics of the Department that the standard of inspection of the same type of engine or machine built by a number of contractors was not consistent. In the case of new firms, and at times even of firms with long standing contracts, such cases did actually arise by intention. It was soon found with some contractors that if the least relaxation of standard requirements were permitted, the whole quality of that firm's production immediately fell away, their aim being merely to make an article "good enough to pass A.I.D.," irrespective of whether it fulfilled all requirements or represented their best effort. In the long run, therefore, it was both expedient and economical to reject parts which, though not to drawing, might have been made serviceable, in order to maintain the general quality of the firm's work, and prevent a subsequent serious increase of rejection.

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[1] A.S. 30638/1917.
[2] (Printed) *Weekly Reports, passim.*

(c) Supply of Working Drawings.

During 1917 the complaints of delay due to lack of drawings were as frequent as those due to modifications. The Drawing Office of the Technical Department was formed by the amalgamation of three small drawing offices, one of which originated at the Admiralty Air Department and was engaged upon the design of experimental seaplanes, boat seaplanes and engines, and the other two formed part of the War Department. The two latter had been established in 1916 as parts of the technical branches dealing with aeroplanes and engines. In the early days of the war, draughtsmen with aeronautical experience were unobtainable and men with good mechanical experience were selected. This shortage of draughtsmen continued throughout the war, and was one of the main causes of the difficulty in providing drawings.

The designing firms at the beginning of the war had all the defects of pioneers in an industry which was in its infancy. Before the war an order for more than a score of machines to the same design was a very unusual event. Working drawings were almost unknown: sketches and verbal discussions in the shop were very much the rule. The designer, chief draughtsman and works foreman worked in close touch with each other and great flexibility in the experimental stage was obtained. But when the war demanded production in quantity this system broke down. Until May, 1917, the Admiralty method by which the designing firms were relied on to provide drawings for the contractor was continued. The disadvantages of this system showed themselves when production reached large figures. It was found that the original drawings were incomplete and full of inconsistencies, errors and defective detail, and the time required to deliver the sets might extend over 12 months. These were corrected, completed and modified by each firm in collaboration with the resident production, inspection and technical officers, and the results were not favourable to bulk production. There were existing at one time about 30 variants on an alleged standard machine. The function of the drawing office set up under the Technical Department of the Air Board was to obtain complete sets of working drawings, and to issue drawings to contractors. Second in importance to setting up a standard set of drawings was the work of embodying the stream of modifications imposed by the Services and technical officers. For this work the available staff was always inadequate both in quality and quantity. There were never sufficient first-class men to fill the various posts of responsibility. In spite of these abnormal conditions, the drawing office set up an effective routine for producing and maintaining complete working drawings for all types. So great was the volume of work that in 1918 decentralisation of drawing office work was arranged, and the system of parent firms adopted by the Admiralty from the beginning was reverted to. Designs were entrusted to certain firms—not necessarily those which produced the original design—for the purpose of embodying modifications and producing working drawings. The reluctance with which firms undertook this work is an indication of the difficulty of developing and maintaining an efficient drawing office organisation for production purposes under war conditions. The method, however, materially assisted the work of prepaiing standard drawings.

III. Review.

Certain of the difficulties which attended the production of aircraft at the opening of hostilities were common to all munitions of war. Such were the lack of man-power, the improvisation of organisation, and the dearth of suitable factories, plant and machinery. Aircraft manufacture had the great additional disadvantage of being an infant industry. It lacked experience in manufacture and it lacked knowledge of the application of the new arm to actual warfare. The only British aero-engines available in any quantities on the outbreak of war were the 100-h.p. Green and the 8-cylinder and 12-cylinder Sunbeam. These were water-cooled engines, and their weight and petrol consumption were high, making them unsuitable for aircraft work. Importation of engines and manufacture in England of foreign designs therefore became essential and for the first two years of the war both the Royal Flying Corps and the Royal Naval Air Service were almost entirely dependent on engines of French design, large numbers of which were actually built in France. A still more serious difficulty was British dependence on Germany for magnetos, and this had a most adverse effect upon engine supply for the first two years of war. Before the war no special study had been made of the problem of selecting the most suitable material for the manufacture of aircraft and aero-engines, with the result that much research had to be devoted to this subject during the course of the war, and engine design especially was retarded owing to the difficulty of finding suitable material for crankshafts. Much work was also necessary on carburetters and radiators before designs suited to the peculiar conditions of aircraft could be developed. The position with regard to aeroplanes was hardly less serious. The B.E. machines were the only British designs capable of being put into production rapidly, and until the end of 1916 the number of French machines used by both Services was very large.

The organisation for securing technical progress had been fostered by the War Department at the Royal Aircraft Factory, Farnborough. Though formed originally to deal with balloons this establishment had taken over the function of designing aeroplanes, and in this work it had been very successful. Naval policy had always lain in the direction of fostering the development of machines by the trade, and on the outbreak of war the design section of the Royal Naval Air Service was in its infancy. Throughout the war full use was made of the capacity of private designers. A large amount of research work on aeronautical problems of all descriptions was carried out by the National Physical Laboratory and other bodies, and through the Advisory Committee for Aeronautics, which had been appointed in 1909 under the presidency of Lord Rayleigh to advise the Government on matters connected with flight, the results of this work were made known to the trade. Thus, by the beginning of 1916 the aircraft industry was fully capable of undertaking original design of machines, and the various technical authorities confined themselves chiefly to research on the special problems which arose in the course of the progress of the science of aviation.

The separation of the technical branches of the two Services has often been characterised as indefensible. It must, however, be borne in mind that aircraft and its armament tended to develop along different lines for the two Services. Speed and manœuvrability and a high ceiling were needed for Army aeroplanes, while reliability and air endurance were the principal characteristics required by the Navy. In the case of kite balloons great strength was the chief requirement of the Royal Naval Air Service, while lightness and portability were essential for the Royal Flying Corps. Kite balloon design and supply was until July, 1916, entirely in naval hands, and it was on account of the difference in their requirements that the War Department took over supply in 1916. In the absence of any unbiassed authority to provide material for both Services, independent supply was undoubtedly the only solution, as a centralisation in either one or the other would have led to development of types required by one Service at the expense of the other. In the Ministry of Munitions the necessary independent neutral was found, and much standardisation between the types used by the two Services was found possible without impairing their usefulness for either Service.

The greater number of the best aeroplanes used during the war owe their origin to the efforts of the Admiralty and War Departments, but a great deal of design work was necessary during the period 1917-18 before these machines were suited for production in quantity, and various alterations were necessary to adapt them to the engine situation. A further complication in the matter of design was the ever-increasing demand for extra equipment by the forces in the field. More ammunition, more guns, electrical equipment, cameras, extra bombs and gear, a better field of fire, a better view for bomb sights, all these were asked for from time to time and provision had to be made to incorporate these requirements in aircraft in process of construction. As a rule, the final type as it appeared in the field differed widely from the first experimental machine. These demands were due to the extraordinary growth in the duties required of aircraft as the war progressed. The original function of reconnaissance quickly extended to fighting, artillery co-operation, bombing and ground fighting. Besides carrying greatly increased loads, aeroplanes were required to fly faster and to climb both faster and higher. The development of anti-aircraft gunnery made it essential that aeroplanes should carry out their work at altitudes never contemplated before the war. This entailed extra equipment such as oxygen and heating gear, and introduced many problems into the already complicated matter of aero-engine design.

The methods adopted by the Admiralty and War Department for securing supplies of aircraft had many points of diversity. In the Admiralty scheme of supply the work of production was under the control of officers who were also responsible for technical matters and inspection. The Directorate of Military Aeronautics provided for separate branches responsible for supply and inspection, the technical functions being shared by the Royal Aircraft Factory and the

Inspection Department. Inspection by Admiralty officers was based on selection: the War Department insisted on detailed inspection. The supply branches of both Departments accepted responsibility for the final flight tests, and thus cemented the interests of the staff in the service value of their productions. The success of the Service methods of supply is clearly shown in the figures of output in the annexed tables.[1] The home output of engines for the last five months of 1914 was 99, while in 1915 the total home output was 1,721 and in 1916 5,363. The total of engines supplied to the Services rose from 2,632 in 1915 to 7,227 in 1916, the number of foreign engines supplied being doubled in 1916. The increase in aeroplane output was no less remarkable. The home output increased from 193 (August to December, 1914) to 1,681 in 1915 and 5,716 in 1917. The number of foreign aeroplanes was not so great as of engines, the figures for 1915 and 1916 being 661 and 917 respectively. The progress in development of seaplanes and ship aeroplanes during the period was slow. The early years of the war were devoted largely to experimental work on seaplanes, and the evolution of a satisfactory type was to a great extent dependent upon the development of suitable engines. The ship aeroplane was still at the trial stage at the end of 1916. Boat seaplanes were obtained almost entirely abroad, from America and France.

The organisation for supply under the Ministry of Munitions followed the same general lines as the existing organisation at the Directorate of Military Aeronautics, most of the branches continuing to exist under new names with additional staff from the Naval Service, thus retaining a Service atmosphere in the new department. The Controller profited by Service experience, adopting with slight modifications the Army method of inspection, which, owing to its more detailed character, was more suited to the projected developments in manufacturing capacity, and the Admiralty policy of design, which threw the responsibility for initiating design upon the designing staff of private firms. The growing control over materials and components involved certain changes in contract and accounting methods, but the only outstanding change of policy was the concentration on larger units, and the development of national factories. The adoption of this policy was partly due to the shortage of adequate supervising staff to cope with the ever-increasing influx of unskilled labour into the industry, and partly to the complications arising in finance, accounting and allocation of material, consequent on the employment of a large number of small firms. This policy was justified by experience. In March, 1917, the number of main contractors for complete aeroplanes was 49, while in March, 1918, it was only 57 and output had been practically trebled. But the national factories were started at such a late period of the war that maximum output was never attained and their contribution to the total aeroplane output was practically negligible. The Radiator Factory at Greet was, however, found invaluable for emergency work owing to the peculiar conditions existing in the private radiator firms.

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[1] See pp. 173-174.

The shortage of inspecting staff necessitated some modifications in Army methods of inspection as mentioned above. A system of selective inspection became necessary. Under this arrangement the whole output of the firm was inspected in detail by the contractor's own viewing staff and only a proportion of that output was re-examined by the Aeronautical Inspection Department, who, however, supervised the firms' methods of inspection and required fulfilment of certain standard conditions. Such a system had frequently been suggested in the earlier part of the war, in most cases by the contractors themselves, but in general the contractors had no true appreciation of the responsibilities involved in inspection, or the training and size of staff required to carry it out. It was only possible to introduce the selective system as a gradual process, concurrently with the development of experience of the firm's *personnel.* It was not, for this reason, introduced simultaneously at all contractors' works: indeed certain firms were never capable of assuming the responsibility, and the degree of selection carried out by the Inspection Department varied with almost every firm. The basis of this inspection was the checking of those dimensions of a part or component which governed safety, but which were not automatically cared for by the manufacturer and his own staff as affecting ease of erection. For instance, the checking of the diameter of the connecting rod big-end could safely be left to the contractor, as any error would be detected when fitting the rod to its crankshaft. On the other hand the thickness of the web of the connecting rod in no way affected the fitting but did affect its safety. It was therefore on such points that the selective inspection was concentrated. The asumption by contractors of part of the responsibility for their productions had on the whole a most beneficial effect. The firms soon discovered that detailed inspection during manufacture was an essential process of production and led to increased output and diminished waste. No less important was the educational value of the enforcement of honest and accurate workmanship on the large staff of young people of both sexes employed by the aircraft firms.

The achievements of the Ministry of Munitions are shown in the annexed tables of deliveries. Total deliveries of aeroplanes increased from 6,633 in 1916 to 14,832 in 1917 and 30,782 in 1918. Home output increased from 5,716 in 1916 to 13,766 in 1917, and 30,671 in 1918. Analysis of the figures shows an extraordinary increase in the production of single-seater machines during 1917. The home output of these machines was 706 in 1916 and 4,642 in 1917, and consisted chiefly of the Sopwith productions and the S.E.5. The development of the twin-engine bombers during 1918 was even more remarkable, the numbers produced increasing from 30 in 1917 to 391 in 1918.

The home output of seaplanes, ship aeroplanes and boat seaplanes was greatly increased during 1917 and 1918. Demand for this craft increased very rapidly during 1917 owing to the submarine menace, and satisfactory types having been evolved by the middle of 1917, it was impossible to put them into bulk production, but the importation of American boat seaplanes was considerable up to the end of the war.

The failure to produce engines in accordance with the programme during 1918 can hardly be brought as an accusation against the Supply Department, as the programme was embarked upon under protest. Although the shortage of engines was rather a deficiency in certain types than in total output, nevertheless squadron development was seriously hampered by the supply position during the last 6 months of the war.

The output of 4,000 engines per month, aimed at during 1918, was never reached. Maximum total output (8,261) was attained during the first quarter of 1918, owing to a large importation of French rotary engines during that period. Home output reached a maximum in the third quarter of 1918, the total for that quarter being 5,905. The output, both total and of home production, was more than doubled during 1917, and in 1918 the 1917 output was again nearly doubled.

OUTPUT OF AEROPLANES, SEAPLANES AND FLYING BOATS. AUGUST, 1914, TO DECEMBER, 1918.*

	1914. Aug. to Dec.	1915.	1916.	1917.	1918.	Total.
AEROPLANES.						
Single-Seater—						
Home	30	224	706	4,642	11,481	17,083
France	—	67	173	587	39	866
Two-Seater—						
Home	103	1,423	4,953	9,037	18,721	34,237
Abroad	4	580	737	467	70	1,858
Experimental—						
Home	60	34	46	57	72	269
France	3	14	7	12	2	38
Twin-Engine Bombers	—	—	11	30	391	432
Four-Engine Bombers	—	—	—	—	6	6
Total—Home ..	193	1,681	5,716	13,766	30,671	52,027
Abroad..	7	661	917	1,066	111	2,762
Grand Total ..	200	2,342	6,633	14,832	30,782	54,789
SEAPLANES AND SHIP AEROPLANES.						
Home	52	250	430	910	936	2,578
Abroad	—	12	—	—	2	14
Total ..	52	262	430	910	938	2,592
BOAT SEAPLANES.						
Home	—	2	3	72	411	488
Abroad	4	75	21	75	100	275
Total ..	4	77	24	147	511	763

* For Home output the figures up to May, 1917, represent the numbers "handed to services." From June, 1917, to December, 1918, they represent "passed inspection." For other than British manufacture the figures represent "handed to services."

OUTPUT OF AERO-ENGINES. AUGUST, 1914, TO DECEMBER 1918.*

	1914.	1915.	1916.	1917.	1918.	Total.
STATIONARY WATER-COOLED.						
Home	51	545	1,500	4,945	11,630	18,671
Abroad	4	111	322	2,344	6,530	9,311
Total ..	55	656	1,822	7,289	18,160	27,982
STATIONARY AIR-COOLED.						
Home	13	820	2,339	3,288	2,936	9,396
France	16	221	630	198	159	1,124
Total ..	29	1,041	2,969	3,486	2,995	10,520
ROTARY.						
Home	31	350	1,500	3,504	7,508	12,893
France	15	567	912	2,326	2,582	6,402
Total ..	46	917	2,412	5,830	10,090	19,295
EXPERIMENTAL.						
Home	4	6	24	26	14	74
France	4	12	—	34	10	60
Total ..	8	18	24	60	24	134
Total Home	99	1,721	5,363	11,763	22,088	41,034
Abroad ..	39	911	1,864	4,902	9,181	16,897
Grand Total	138	2,632	7,227	16,665	31,269	57,931

* For Home output the figures up to May, 1917, represent the numbers "handed to services." From June, 1917, to December, 1918, they represent "passed test." For other than British manufacture the figures represent "handed to services." With the exception of French engines deliveries do not include spares.

Figures of output do not, however, convey even an approximate idea of the actual achievement of the departments concerned in aircraft production. From the comparatively simple structure of the pre-war aeroplane, technical evolution of aircraft had, by the end of the war, produced a complicated weapon involving in its production the co-operation of innumerable craftsmen. New industries had been set up and existing ones developed to an incredible extent. Aircraft construction was in its infancy in 1914, and the aero-engine building industry was practically non-existent. The manufacture of magnetos was confined to one English firm, and the few aircraft instruments then required were produced by very few manufacturers. At the end of the war aero-engine production was a huge industry involving innumerable firms of large and small capacity, and British engines have outstripped the productions of all other countries in reliability and efficiency. The advances made in magneto production were particularly remarkable, both as to quality and quantity. Instead of one firm producing 1,140 magnetos yearly as was the case in 1914, some 14 firms were at the end of the war producing 128,637. Bourdon tubes for pressures gauges were not obtainable in the United Kingdom until a firm of gold refiners undertook their

manufacture with success, and revolution indicators had not been made by British manufacturers before the war. These results could not have been attained had it not been for the skill, courage and ingenuity shown by the various pioneer firms and their designing staffs.

The Ministry was confronted not only with the problem of creating capacity for the production of the innumerable parts which compose the modern aeroplane, but of so controlling supplies of material and rate of output that supply was synchronised over the whole field, for the failure of one component had far reaching effects over the whole organisation of supply. The enormous quantities of materials dealt with may be exemplified by the figures relating to the output of linen and timber. In 1918 over 59,000,000 yards of linen cloth were produced, and the total quantity of aeroplane spruce and substitutes delivered to aircraft contractors from 1 July, 1917, to 11 November, 1918, amounted to 45,750 standards. The shipping tonnage involved will be appreciated when it is realised that a standard weighs 2½ tons and contains 165 cubic feet.[1] Though it would be absurd to claim that absolute concurrency of output was obtained, the figures of deliveries show that it was accomplished to a large extent. It was only on rare occasions that delivery was accepted of an incomplete machine, although the provision of the right kind of engine for the various types was invariably a matter of extreme difficulty. The problem of supply was throughout the war complicated by the experimental nature of the stores dealt with, and the development of design concurrently with production entailed numbers of alterations in almost every part of a machine during its progress through the workshop. This difficulty was greatly increased by the lack of experienced skilled labour, and without the loyal co-operation of firms and works managements the output actually attained could never have been reached.

It is difficult to over-estimate the advances which were made during the war by the industries subsidiary to aircraft production. Researches in metallurgy and chemistry were fostered by the enormously increased demand for machines of high quality. The research on alloy steels carried out in connection with engine specifications is of lasting value, and the development of strong light-weight tubing has paved the way for metal construction of aeroplanes. Experiments conducted upon chemicals used in dope manufacture have resulted in the production of strong pliable non-inflammable films which will be useful for many purposes in post-war industries. The advantages derived from the improvement in petrol-resisting rubber tubing and in the quality of oil and petrol are not solely confined to the aircraft industry. The specifications of aircraft materials drawn up during the war have been adopted practically unaltered by the British Engineering Standards Association, and there is no doubt that the fundamental principles upon which the production of interchangeable components was based are applicable to almost any mechanical article manufactured in quantities. Consequently the pioneer work done by

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[1] HIST. REC./H/1960/2.

the Aeronautical Inspection Department has been a factor in modernising the production methods of the country. In the metal trades the growth during the war was enormous. Skilled die-casting can save a large expenditure in machining. Its products can be guaranteed to very fine limits, and when chemists and metallurgists had produced alloys and metal particularly suited to die-casting, very marked advances were made and manufacturers began to consider the advisability of purchasing parts which needed practically no machining and could be guaranteed for density, durability and size. The stamping and forging industries also grew rapidly, quantity production giving them an opportunity for development which had not presented itself before the war, for the expense lies more in making the complicated dies and punches than in the actual work when the preliminary tools are completed. The work done in the improvement of linen weaving and in the process of scutching should have a permanently beneficial effect on Irish industry, and the production of a cotton fabric equal in many respects to linen is the result of efforts to find a substitute for the latter, for the covering of aeroplane wings.

The contribution of the Allies towards the success of the British air effort has been very great. French assistance was of peculiar value in that it was rendered in the first months of the war, when home industry was incapable of supplying the Services with the necessary equipment. The French rotary engines alone enabled the two Services to carry on through the first two years of war, and such were the qualities of these engines that they were used in increasing quantities throughout the war. The French aeroplanes were also invaluable during the first two years of the war, and the Maurice Farman was the standard training machine until nearly the end of 1917. Italy's contribution consisted in F.I.A.T. engines, which were of high power and helped to relieve the engine situation at the end of 1917 and in the summer of 1918. American help consisted chiefly in supplies of raw material. Timber, chemicals for dope and engineering materials were the chief items. Boat seaplanes were also provided by America, and the Curtiss machines and engines were used in some quantities for training purposes. The Liberty engine was of assistance in equipping the large bombing machines of the last months of the war.

At the date of the Armistice the programme of production was working up to its maximum output. The value of contracts outstanding at the date of the Armistice was £165,000,000, amounting to more than half the total commitments of the Ministry. To meet the Air Council's peace programme the number of aeroplanes and engines required did not amount to more than about three months' output of the programme due at the end of 1918. These facts and the peculiar conditions of the aircraft industry made economical liquidation almost impossible, and the Liquidation of Aircraft Contracts Committee accordingly recommended a large amount of apparently unproductive expenditure. The longer break clauses provided in aircraft contracts made it necessary, failing any agreement to the contrary, to accept and pay for the output during the stipulated periods. The policy

adopted by the Liquidation Committee was to terminate at common law all contracts for obsolete machines condemned by the Air Ministry, even for civilian flying, irrespective of break clauses. In the case of the latest types of machine some contracts were allowed to continue, and others were terminated under the break clause. In the case of machines of which the Royal Air Force would have a surplus under the break clauses, but which would fetch a price in the open market for civilian flying, the committee accepted the fewest possible consistent with a sound economical bargain for the Government. Under an agreement with the United States Government, 1,270 Liberty and 1,500 Eagle VIII engines, which were manufactured in America, had to be accepted, though only about 250 Liberty and 500 Eagles were required. The deliveries taken of aeroplanes amounted to a large proportion of the full value of the contracts at the time of the Armistice, so that little compensation was necessary, but in the case of engines, deliveries taken were only a small proportion of the orders and compensation was accordingly higher.[1] The contracts for engines in France were settled by the French Government taking over the whole liability of the British Government under the contracts in exchange for a lump payment, since none of the engines were required for the peace programme.

[1] D.M.R.S. 467 G.

APPENDICES.

APPENDIX I.

(CHAPTER V, p. 127.)

The Flax (Control) Order, 1917, dated 25 August, 1917, made by the Minister of Munitions.

The Minister of Munitions, in exercise of powers conferred on him by the Defence of the Realm Regulations and all other powers thereto enabling him, hereby gives notice and orders as follows :—

1. He hereby takes possession as from the date hereof of—
   (*a*) All flax of the 1917 crop grown in the United Kingdom, as and when harvested.
   (*b*) All flax grown in the United Kingdom at any time and not at the date hereof in the possession of a flax spinner, for the purposes of his business.
   (*c*) All other flax, except Russian flax, now or hereafter situated in the United Kingdom.

2. The flax, of which possession is hereby taken under para. 1 (*a*) and (*b*), will be divided under the directions of the Controller of Aeronautical Supplies into six grades, according to the quality, handling and cleaning, and the Minister will pay the following prices therefor :—

Special	grade,	35s. 0d.	per stone delivered at the appointed centre.
1st	,,	32s. 6d.	,, ,, ,, ,, ,,
2nd	,,	30s. 0d.	,, ,, ,, ,, ,,
3rd	,,	27s. 6d.	,, ,, ,, ,, ,,
4th	,,	26s. 3d.	,, ,, ,, ,, ,,
5th	,,	25s. 0d.	,, ,, ,, ,, ,,

Flax which is inferior in quality to that of the fifth grade hereinbefore mentioned will be paid for upon terms which will be subsequently communicated to the various owners.

3. If after this Notice and Order any person having control of any flax of which the Minister has taken possession hereunder sells, removes or secretes such flax without the consent of the Minister, he will be guilty of an offence against the Defence of the Realm Regulations.

4. No person shall, as from the date hereof, until further notice, purchase, sell, offer to purchase or sell, or, except for the purpose of carrying out a contract in writing, existing prior to the date hereof, for the purchase of such flax, enter into any transaction or negotiation in relation to the sale or purchase of any flax situated outside the United Kingdom.

5. Further directions with regard to the delivery of flax, of which possession is taken hereunder, will shortly be issued on behalf of the Minister by the Controller of Aeronautical Supplies.

6. All communications upon the subject of this Notice and Order should be, for the present, addressed to the Controller of Aeronautical Supplies, and marked Flax Supplies, Department S. (M.A.), 1, Air Board Office, Strand, London, W.C. 2.

APPENDIX II.

(CHAPTER V, p. 128.)

The Re-Scutched Tow Order, 1918, dated 28 February, 1918, made by the Minister of Munitions.

The Minister of Munitions, in exercise of the powers conferred upon him by the Defence of the Realm Regulations and of other powers thereunto enabling him, hereby gives notice and orders as follows :—

1. He hereby takes possession, as and from the date hereof, of all re-scutched tow off the flax of the 1917 crop and previous years grown in Ireland and not at the date hereof in possession of a flax spinner for the purpose of his business.

2. The re-scutched tow, of which possession is hereby taken, under para. 1, will be divided under the direction of the Director-General of Aircraft Production into three grades, according to its quality, handling and cleaning, and the Minister will pay the following prices therefor :—

First Grade.—£100 per ton, delivered at nearest railway station to appointed destination.

Second Grade.—£95 per ton, delivered at nearest railway station to appointed destination.

Third Grade.—£85 per ton, delivered at nearest railway station to appointed destination.

Fine Tow, which is not re-scutched, pluckings, dressings, and re-scutched tow which is inferior in quality to that of the third grade hereinbefore mentioned, will be paid for according to their relative values.

3. All contracts previously entered into for the purchase of re-scutched tow are hereby cancelled as at this date, as regards re-scutched tow not yet delivered.

4. If, after this Notice and Order, any person having control of any re-scutched tow referred to hereunder, sells, removes or secretes such re-scutched tow, except upon the terms provided in this Order, he will be guilty of an offence against the Defence of the Realm Regulations.

APPENDIX III.

(CHAPTER V, p. 128.)

The Scutch Mills (Ireland) Order, 1918, dated 17 May, 1918, made by the Minister of Munitions.

The Minister of Munitions, in exercise of the powers conferred upon him by the Defence of the Realm Regulations and all other powers thereunto enabling him, hereby gives notice and orders as follows:—

1. No person owning or controlling any scutch mill in Ireland, wherein flax straw is scutched for any person other than the owner or controller thereof, shall, without a licence issued by or on behalf of the Controller of the Supplies Department of Aircraft Production, scutch or cause to be scutched at any time after the first day of July, 1918, any flax straw.

2. Any person failing to comply with any provision hereof, or with any condition of any licence issued hereunder, shall be guilty of an offence against the Defence of the Realm Regulations.

3. This Order may be cited as the Scutch Mills (Ireland) Order, 1918.

APPENDIX IV.

(CHAPTER V, p. 129.)

I. The Linen Yarns (Control) Notice, 1916, dated 30 December, 1916, made by the Army Council.

In pursuance of the powers conferred on them by the Defence of the Realm Regulations, the Army Council hereby give notice of an intention to take possession of all stocks of linen yarns manufactured partly or wholly from Irish, French, Dutch, or Courtrai flax.

If, after this Notice, any person having control of any yarns of the description aforesaid sells, removes or secretes such yarns without the consent of the Army Council, he shall be guilty of an offence against the said Regulations, provided that nothing herein contained shall prohibit—

(1) The sale of such yarns, in exchange for the guarantee hereinafter required, at a price based upon the price of flax in the Irish markets during the fortnight ending 16 December, 1916 ; and

(2) The delivery of such yarns, in pursuance of any contract entered into prior to the date hereof, in exchange for a guarantee by the purchaser or consignee that the yarns are required, and will be used directly or indirectly for the purpose of any Government contract or order.

By Order of the Army Council,

R. H. BRADE.

II. The Linen Yarns (Control) Amendment Notice, 1917, dated 5 January, 1917, issued by the Army Council. Army Council Notice as to Linen Yarns under the Notice of 30 December, 1916.

In pursuance of the powers conferred upon them by the Defence of the Realm Regulations, the Army Council hereby give notice—

(1) That nothing in the Notice of the Army Council with respect to linen yarns, dated 30 December, 1916, applies to yarns spun from flax tow.

(2) That nothing in the proviso of the said Notice refers to any yarns suitable for manufacture into any cloth suitable for aeroplane work.

If, after this Notice, any person having control of any yarns of the description aforesaid, sells, removes or secretes such yarns without the consent of the Army Council, he shall be guilty of an offence against the said Regulations.

By Order of the Army Council,

R. H. BRADE.

III. The Linen Yarns (Spinning) Order, 1917, dated 5 January, 1917, made by the Army Council.

In pursuance of the powers conferred upon them by the Defence of the Realm Regulations, the Army Council hereby order as follows :—

1. It is hereby required that in all factories, workshops, or other premises engaged or to be engaged upon spinning linen yarns, the work shall be done in accordance with the following directions ; that is to say :—

(*a*) No flax which can wholly or partly be used for spinning into yarns for the manufacture of any cloth suitable for aeroplane work shall be used otherwise than for the manufacture of cloth of the description aforesaid, save and except as may be authorised and permitted by or on behalf of the Director of Aircraft Equipment.

(*b*) Returns shall be made by the owners or occupiers of such factories, or workshops, their officers and servants, as may be required by or on behalf of the Director of Aircraft Equipment.

(*c*) Any directions that may be given for the purpose of this Order by or on behalf of the Director of Aircraft Equipment, shall be strictly complied with by the owners or occupiers of such factories or workshops, their officers or servants.

2. It is hereby required that all persons having in their custody or control any stocks of Courtrai flax, whether spun or unspun, and whether sold or unsold, shall make a return within four days hereof, addressed to D.A.E.4 S.3, War Office, Adastral House, London, E.C. 4, giving all particulars of such stocks as may be required by or on behalf of the Director of Aircraft Equipment.

By Order of the Army Council,

R. H. Brade.

APPENDIX V.

(Chapter V, p. 143.)

The Oxygen Order, 1917, dated 17 December, 1917, made by the Admiralty.

The Lords Commissioners of the Admiralty, in exercise of the powers conferred upon them by the Defence of the Realm Regulations and all other powers thereunto enabling, and with the concurrence of the Army Council and the Minister of Munitions, hereby order that, from and after the date of this Order and until further notice, the sale and supply of oxygen in the United Kingdom shall be regulated in accordance with such directions as may from time to time be given by the Director of Materials and Priority, Admiralty; and hereby order and require as follows :—

1. No person or company manufacturing or supplying oxygen shall sell or supply the same otherwise than to such persons or companies and in such quantities as the said Director of Materials and Priority shall from time to time direct.

2. All persons and companies manufacturing or supplying oxygen for sale or for their own use, and all persons and companies requiring to purchase oxygen, shall render such full and accurate returns as the said Director of Materials and Priority shall from time to time direct.

3. Any failure to comply with any restriction or condition imposed, or with any directions given hereunder, will be an offence against the Defence of the Realm Regulations.

Given under our hands this 17th day of December, 1917.

Lionel Halsey.
A. G. Anderson.

APPENDIX VI.

(CHAPTER III. p. 66.)

Administrative Organisation of the Departments of Aircraft Production, November 1918.[1]

SIR ARTHUR McD. DUCKHAM, K.C.B.

(Council Member for Air Group, Ministry of Munitions; Member of Air Council, Air Ministry.)

AIR GROUP (Headquarters Staff, 4333).

(1) *Aircraft Requirements and Review* (Controller: Mr. J. W. Gibson, O.B.E.).—Sections: (*a*) General Correlation, Statistics, Reports and Interdepartmental Correspondence; (*b*) Foreign Aircraft Services.

(2) *Technical* (Controller: Brig.-Gen. J. G. Weir, C.B.E., C.M.G.).—Sections: (*a*) Applied Design; (*b*) Aircraft Armament; (*c*) Design; (*d*) Experiment and Research. (Headquarters Staff, 1633.)

(3) *Supply and Production* (Controller: Brig.-Gen. Sir W. Alexander, K.B.E., C.B., C.M.G., D.S.O.).—Sections: (*a*) Aeroplanes; (*b*) Aero engines; (*c*) Seaplanes; (*d*) Propellers; (*e*) Materials and Accessories; (*f*) General Supply Services, including Priority and Labour; (*g*) Statistics; (*h*) Salvage; (*j*) Accounts (Advisory). (Headquarters Staff, 1480.)

(4) *Aeronautical Inspection* (Controller: Brig.-Gen. R. K. Bagnall-Wild, C.B.E., C.M.G.).—Sections: (*a*) Administrative; (*b*) Aeroplane (including: (i) aeroplanes; (ii) aircraft accessories; (iii) seaplanes; (iv) non-metallic materials; (v) general services and equipment). (Headquarters Staff, 1149.)

(5) *American Assembly and National Aircraft Factories* (Controller: Mr. Alexander Duckham).

(6) *Washington Office* (Representative: Brig.-Gen. J. D. Cormack, C.B.E., C.M.G.).

(7) *Paris Office* (Representative: Lt.-Col. E. R. Peal, O.B.E., D.S.O.).

SECTIONS OF OTHER DEPARTMENTS ATTACHED TO AIR GROUP.

Aircraft Finance (Controller: Mr. W. E. Mortimer), reporting to Controller of Finance.—Sections: (*a*) Loans and Assisted Contracts; (*b*) Factories—Finance and Accounts; (*c*) Foreign Contracts. (Headquarters Staff, 59).

Aircraft Accounts (Assistant Controller: Mr. H. M. Barton), reporting to Controller of Munitions Accounts.—Sections: (*a*) Contractors' Bills and Accounts; (*b*) Contract Notings; (*c*) Advances; (*d*) Invoicing Free Issue.

Aircraft Contracts (Controller: Sir T. D. Nicol, K.B.E.), reporting to Controller Munitions Contracts.—Sections: (*a*) Engines; (*b*) Aeroplanes; (*c*) Materials; (*d*) Trades Records; (*e*) Seaplanes and Kite Balloons; (*f*) Rolls-Royce Engines; (*g*) Costing. (Headquarters Staff, 437.)

Aeronautical Stores (Controller: Mr. T. A. Mackenzie), reporting to Deputy Controller, Central Stores Department.

Inland Transport (*Aircraft*), reporting to Director of Munitions, Inland Transport.

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[1] Based upon HIST. REC./H/1960/2, Chapt. IV; HIST. REC./R/263.91/2.

INDEX.

Key to Abbreviations used in Index :—

Ad. = Admiralty.
A.I.D. = Aeronautical Inspection Department.
D.A.P. = Department of Aircraft Production.
D.A.S. = Department of Aeronautical Supplies.
Dir. of M.A. = Directorate of Military Aeronautics.
M. of M. = Ministry of Munitions.
W.O. = War Office.

VOLUME XII

THE SUPPLY OF MUNITIONS

PART II

AERIAL BOMBS

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CHAPTER I.

THE DEVELOPMENT OF BOMBING.

I. Nature of Bombs.

Aerial bombs may be divided into two classes, high explosive bombs and incendiary bombs. Parachute flares used for signalling, which are also classed as aerial bombs, are among the miscellaneous equipment of aircraft and will be dealt with under "Aircraft Supply."[1]

(a) General Characteristics.

All modern high explosive bombs contain three different types of explosive, *i.e.*, a bursting charge, a primer or exploder, and a detonator or cap. The bursting charge is always some safe and insensitive explosive such as T.N.T. or amatol, which can only be detonated by a violent explosion, and consequently all bombs must be fitted with a primer or exploder. The latter contains tetryl, an explosive resembling T.N.T. but more sensitive and easily exploded by a detonator. Detonators all contain fulminate of mercury, a very sensitive explosive, and are fired by being struck or pierced by the striker of the fuse. In nose fuses this detonator is in contact with a primer and no further detonators are needed, though to ensure detonation they are generally used in the exploder. In tail fuses there is generally a considerable distance between fuse and exploder, and the cap in the fuse fires one end of a piece of safety or instantaneous fuse. The other end of this is crimped into a detonator, which sets off the detonator in the exploder. In the nose fuses the striker spindle is the first portion of the bomb to hit the ground, and the striker is driven directly on to a detonator or cap which ignites the exploder. These fuses are practically instantaneous and bombs fired by them explode on impact and so do not enter the ground, but fragments of the bomb are scattered over a wide area. Consequently nose fuses are used only in heavy case bombs, for attacking *personnel* and light structures.

All tail fuses have a delay action, because they act only after the whole bomb has had its speed considerably reduced by meeting with some resistance. When the bomb has been slowed up, the striker which still travels with its own momentum hits the cap of the igniter and fires the bomb. Consequently all bombs fired by a tail fuse bury themselves in the ground before exploding and produce a crater. Tail fuses are therefore used with light cased bombs or as safeguards against the failure of a nose fuse. The periods of delay action can be varied, and those in use are ·05 sec., 2·5 sec. and 15 sec. When a definite time delay or crater effect only is desired, a tail fuse only is employed, but the later practice has been to fit all high explosive bombs with fuses of each type. In the case of cast-iron bombs, which are liable to break up on impact, two fuses are essential. This fusing arrangement

[1] Vol. XII, Part I.

is peculiar to aircraft bombs. The fuses developed towards the end of the war were so designed that the shearing pin of the nose fuse should not be sheared on impact with a roof in an attack on buildings, but the tail fuse is so arranged that under these conditions it will function with a delay action, thus producing an explosion within the structure.

The explosive used in the filling of aerial bombs is amatol, a mixture of trotyl (T.N.T.) and ammonium nitrate. It is used chiefly in two forms known as 40/60 and 80/20, the first figure representing the percentage of ammonium nitrate and the second of trotyl. Amatol is used instead of pure trotyl on account of the comparative scarcity and costliness of the latter. The main mass of explosive in the earlier types of bomb, as issued until the early part of 1916, was either pure trotyl or 40/60 amatol, but most modern bombs are filled with 80/20 amatol. Towards the end of the war 70/30 and 60/40 were adopted as alternative for 80/20. Bombs filled with T.N.T. or 40/60 amatol are cast filled, *i.e.*, the mixture is melted and poured in, while those filled with 80/20 amatol are stem filled, the dry powdered mixture being pressed in. The difficulty of obtaining a satisfactory amatol filling for aerial bombs was less than was the case with other projectiles,[1] for owing to the low speed of a bomb in comparison with that of a shell the problem of "set back" (which added to the density of the filling and the difficulty of detonation in the case of shell) did not arise. The comparatively low velocity of the bomb also made it unnecessary to use the highest grade materials for the body, since the great stresses set up in a high velocity projectile were absent. This was not realised at the outset, and the adoption of cast iron and steel alloy was brought about only by the pressure of circumstances when economy in the use of steel became necessary at the end of 1916.

Incendiary bombs are used for firing buildings, forests, or crops, or for air bursts in attack on kite balloons. They can be burst at any desired height below an aeroplane, and the latest type of 40-lb. incendiary bomb spreads out a shower of burning phosphorus over a circle about 250 yards in diameter. The incendiary compositions in use early in the war were black powder, carcass composition, trotyl and petrol and phosphorus, and they were contained in cases of tin-plate. Thermit, or cendite, the mixture used in the 'Baby' incendiary bomb, is any metallic oxide mixed to a fine powder with aluminium. Towards the end of the war a caseless bomb was produced, composed of thermalloy formed in a mould to the required shape and dimensions.

With high explosive bombs, experience has shown that the larger bombs are more effective than an equal weight of a smaller type. With incendiary bombs the exact opposite is the case, the provision of the maximum number of chances of hitting the target being of great importance. The usefulness of the early types of incendiary bomb was much limited for this reason, and the 'Baby' incendiary bomb (6½ oz. size) was designed to overcome this disadvantage. Its

[1] **For a full account of the development of the amatol mixtures see Vol. X, Part II, Chap. I.**

principle follows that of a mortar and projectile complete. The bombs, 660 of which are carried in one drum, are dropped in showers, and spread over a large area.

(*b*) DIFFERENCES IN NATURE FOR LAND AND NAVAL SERVICE.

Since bombs for use over land and water differ considerably in nature, designs for those used in the two services have tended to proceed on somewhat different lines. Naval bombs, primarily intended to defeat the submarine menace, have been constructed on the "mine" principle, namely, the explosion under water of a light case containing a heavy charge, as opposed to the "shell" principle of a heavy case with a small charge, whose destructive effect depends mainly on the fragmentation of the case. In developing these light-cased naval bombs, it had to be borne in mind that, though primarily for use against submarines, on a scouting trip other objectives, such as an enemy cruiser or destroyer, might be encountered, and, in order that the bombs might be effective in such a case, a compromise had to be made between the "shell" and the "mine" type, since the multiplication of types for such chance demolition work was most undesirable. A compromise was arrived at by strengthening the nose of the light-cased bomb, and enclosing a very large primer in a strong containing case, running the length of the bomb to obtain complete detonation, even when the "tamping" effect of the water was absent.[1] The bombs used by the Royal Flying Corps in the early days of the war were all constructed on the "shell" principle, being designed for use against *personnel* and road transport. Large, light-cased bombs for destroying railways and buildings were later developments.

II. Hindrances to Early Development.

Factors which at first tended to hinder the development of aerial bombs were their novelty and the fear of handling absolutely unfamiliar explosives. The simple nature of the early types had a similar tendency, for they were regarded as crude weapons, unworthy of special study, and throughout the war the more urgent necessities of other branches of the art of aerial warfare resulted in comparative neglect of the training of aerial bombers, the tendency being to regard the problem as one merely of lifting, carrying and releasing; whereas, in reality, intelligent training and study were of the utmost importance. The dynamics of the bomb present characteristics essentially different from those of the artillery shell, in that it is independent of propulsive explosives, and its "muzzle velocity" is limited to the aeroplane's ground speed, possibly 200 ft. per second, while that of the shell is measured in thousands of feet per second. In addition, it is released from a comparatively unstable platform. Its proper functioning depends, therefore, on correct handling quite as much as on perfection of design.

[1] *Ordnance Board Annual Report*, 1915, pp. 360, 361.

III. Development of Bombing Machines.

The use of aircraft as a means of carrying explosives over enemy country and destroying places of military and industrial importance was discussed long before the war. Aeroplanes and seaplanes had, however, been designed without much regard to armament, and aircraft had to be adapted so that guns and bombs could be fitted, and forms of armament suitable for use in the air had to be designed. On the outbreak of war only two types of aerial bomb were in existence, weighing 20 lb. and 112 lb. The latter was used only by the navy, the 20-pounder being the only bomb armament for land machines, which were not at that time capable of carrying the heavier bombs. In 1915 the Royal Naval Air Service carried on bombing as part of their operations on the Belgian coast and at the Dardanelles, as well as for anti-submarine work, and the production of aircraft capable of carrying heavier bombs was pushed forward. The most successful was the Short aeroplane with Rolls-Royce engine of 250 H.P., carrying eight 112-lb. bombs under the wings, the only place available. This was used for about a year, when it was superseded by the Handley Page O-100. Very large machines for weight lifting were used by the Royal Naval Air Service earlier than by the military authorities, with the result that naval machines developed in size and bomb carrying capacity more rapidly than machines for land service. A Handley Page with two Rolls-Royce engines was flying in 1915. This machine was fitted to take sixteen 112-lb. or eight 250-lb. bombs in 1916, and when, eighteen months later, the importance of bombing and the advantages of large machines were appreciated, this type was adopted by the land service without any vital alteration.

The following table gives particulars of some of the aeroplanes used for bombing during the war :—

Machine.	*Engine.*	*Crew.*	*Bomb Weight.*[1]	*Date of Test Report.*
B.E. 2c	90 h.p. R.A.F.1a ..	2	220	4–16
B.E. 2d	90 h.p. R.A.F. 1a ..	2	220	5–16
B.E. 2e	90 h.p. R.A.F. 1a ..	2	220	5–16
B.E. 12	150 h.p. R.A.F. 4a ..	1	160	2–16
A.W.	160 h.p. Beardmore ..	2	448	5–16
R.E. 7	160 h.p. Beardmore ..	2	—	5–16
F.E. 2b	120 h.p. Beardmore ..	2	160	5–16
F.E. 2d ..	250 h.p. Rolls-Royce ..	2	160	5–16
Sopwith Bomber..	130 h.p. Clerget ..	1	260	11–16
Martinsyde ..	160 h.p. Beardmore ..	1	—	1–17
D.H. 4	250 h.p. Rolls-Royce ..	2	440	3–17
R.E. 8	150 h.p. R.A.F. 4a ..	2	220	6–17
N.E. 1	200 h.p. Hispano Suiza ..	2	—	11–17
D.H. 9	240 F.I.A.T.	2	280	11–17
Vimy II	Twin Sunbeam Maori ..	3	2000	5–18
D. H. 9a	12 Cyl. Liberty ..	2	460	7–18
D.H. 10	Twin Liberty	3	660	7–18
H.P.O–400 ..	2 Rolls-Royce Eagle VIII	3	1790	7–18
H.P.V–1500 ..	4 Rolls-Royce Eagle VIII	7	6000	9–18

The Handley Page V.1500, the Vimy and D.H.10 did not actually see service.

[1] The bomb weight given in the total weight of bombs for which fittings were provided.

IV. Development of Types of Bomb.

On the outbreak of war little progress had been made in the design of aerial bombs. The types then in use were the Hale 20-pounder and the naval 112-pounder, used with one fuse. The Friedrichshafen and Cuxhaven raids at the end of 1914 were both carried out with 20-lb. bombs.[1] At the end of 1914 the aerial bombs in use were high explosive bombs of R.L. design weighing 112 lbs., 20 lbs. and 10 lbs., and the Cotton Powder Company's 10-lb. and 20-lb. Hale bombs. Trials were being carried out with a bomb of R.L. design made from 12-pounder high explosive shells. The navy used the two types R.L. 112-lb. and Hale 20-lb. bomb. Neither was found entirely satisfactory, the former being too heavy for the majority of machines then in use, and the latter being an inferior weapon in all respects.[2]

During the early months of 1915 development was rapid, the existing types being improved and new ones evolved. The most successful were those designed by the Director of the Air Department in conjunction with the Chief Superintendent, Ordnance Factory, the 16-lb., 65-lb., 100-lb. and 520-lb. light case, and the 550-lb. heavy case.[3] The Cotton Powder Company produced another type weighing 100 lb. by the middle of 1915. In July, 1915, a new design of the 112-lb. bomb, fitted with a central tube, so that nose or tail fuse could be used as desired, was prepared at Woolwich for the use of the Royal Flying Corps.

Experiments were made in the spring of 1915 to determine the best form for a bomb of heavier type, suitable for the destruction of buildings and their contents. As a result of research by Professor Hopkinson, it appeared advantageous that the metal of the case should be disposed in strips thicker in the middle,[4] and the 336-lb. Royal Aircraft Establishment bomb was made on this principle, and used in small quantities. Satisfactory results were obtained with a 500-pounder designed at the Royal Aircraft Establishment, Farnborough, and about the same time three experimental 400-lb. bombs were made. Neither of these types became standardised, and the 112-lb. remained the standard heavy bomb for land service until the evolution of the 230-lb. bomb in November, 1916. A heavy armour-piercing bomb weighing 180 lb. was designed in 1916 and used for special operations. The 20-lb. Hale was discarded by the navy at the beginning of 1915 and the 10-lb. in November of that year.[5] The former was replaced by a bomb of the same weight of R.L. design, usually known as the 16-lb. bomb. The 20-lb. Hale was used in the land service to a later date, though its limitations were recognised, since its size suited the machines of that date and it could not be entirely replaced by the 16-lb. R.L. It was successfully used in the first attacks by Zeppelins

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[1] HIST. REC./H/1960/2.
[2] *Ordnance Board Annual Report*, 1915.
[3] *Ibid.*; HIST. REC./R/1310/3.
[4] *Ordnance Board Annual Report*, 1915.
[5] *Ordnance Board Annual Report*, 1915, pp. 360, 361.

on this country, and it remained the standard defence against Zeppelins until the advent of the Ranken dart.[1]

In August, 1915, the army requirements for aircraft bombs included Hale's 20- and 100-pounders and the R.L. 100- and 112-pounders.[2] In November the 112-lb. bomb superseded the 100-lb. of both types[3] and production was chiefly concentrated on the 20-lb. and 112-lb. bombs. In February, 1916, it was found that the 20-lb. Hale bomb was too small for most of the requirements of the Royal Flying Corps, and large stocks were accumulating,[4] but in September the requirement for this type was raised to 30,000 per month and production was again increased. By this time a satisfactory substitute had been found in the 20-lb. Cooper bomb, the result of private enterprise in design, and in November, manufacture of the Hale bomb was stopped.[5] Until May, 1917, demands for this type were met by the 16-lb. R.L. and 20-lb. Cooper, but then the Cooper bomb was coming forward in sufficient quantities to meet all demands, and production of the 16-pounder ceased.[6]

When in August, 1916, the supply of aerial bombs for the Royal Flying Corps was taken over by the Trench Warfare Supply Department, there were about 20 types in use, including the 585-lb., 400-lb., 336-lb. and 112-lb. of Royal Aircraft Establishment design, 100-lb. and 16-lb. of R.L. design, the Hale 100-, 20- and 10-lb., and the Cooper 20-lb., besides incendiary bombs.[7] By May, 1917, the types being manufactured in quantity had been reduced to 8 or 10, the principal being 230-lb. 112-lb., 20-lb. Cooper, 40-lb. phosphorus incendiary and the 10-lb. carcass incendiary.[8]

In September, 1917, a big scheme of aircraft production was initiated, and aerial bomb supply for both services was vested in a single authority, the Trench Warfare Supply Department of the Ministry of Munitions. The policy then adopted was based on the assumption that only four types were required for land service—(1) a small heavy case bomb for use in attack on *personnel*, aerodromes and road transport, suitable for carrying on light machines; (2) a medium weight heavy case to be used against *materiel* by the smaller bombing machines on long distance raids when full fuel was needed and the use of a heavier type of bomb thus precluded; (3) a large heavy case bomb to be used against *materiel* and for general purposes; (4) a large light case bomb for crater production in attacking railways and buildings. Requirements (1) (3) and (4) were met by the 20-lb. Cooper, the 112-lb. Marks VI and VII, and the 230-lb. light case bomb, respectively. To meet (2), a 50-lb. heavy case bomb was designed, for manufacture in cast iron (no steel being then available). A new design

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[1] Hist. Rec./H/1960/2.

[2] 94/B/120, 146.

[3] 94/B/564.

[4] T.W./5625; 94/B/943.

[5] T.W./6933.

[6] (Printed) *Weekly Report*, No. 90. IX. (5/5/17).

[7] Hist. Rec./H/1610/16.

[8] Hist. Rec./H/1610/16.

of 112-lb. bomb was also produced in cast iron at this time, and the adoption of this material for heavy bombs marks a revolution in preconceived ideas on this subject without which supply on the scale required would have been impossible. These four types became the standard aerial bombs, but since at the same time it was decided to use chiefly the 112-lb. at the front and the 20-lb. for raiding Germany, these two types continued to absorb attention somewhat to the disadvantage of the heavier natures. The naval branch were using heavier types (230-lb. and 520-lb.), but these were light cased bombs used chiefly in anti-submarine work. The Handley Page bombing machines of that date carried sixteen 112-lb. bombs, but experience has shown that with high explosive bombs the maximum damage weight for weight of bombs dropped is produced by the larger bombs, and the tendency has since been to increase the sizes.[1] In the early months of 1918 larger bombing machines were being constructed and the uses of the 520-lb. light case and 550-lb. heavy case were developed. These were both of R.L. design.[2] In addition, experiments were carried out with 1,400- and 1,650-lb. bombs, and the S.N. 1,700-lb. emerged about February, 1918.[3] A super S.N., weighing 30 cwt., was designed at the end of the war, but was never used.[4]

The types of high explosive bomb in existence at the end of the war were 20-lb. Cooper, 50-lb., 112-lb., 230-lb., 250-lb., 336-lb., 520-lb., 550-lb., S.N. (1,700-lb.) 100-lb. and 65-lb., and the 9·45-in. converted trench mortar bomb.[5]

An interesting feature in the development of bombs has been the progress made in the incendiary types. While explosive bombs were naturally given the greatest attention, the incendiary bomb was greatly improved, and later on its potentialities for destruction were more fully appreciated. Until 1916 this method of warfare had not been definitely studied. Systematic experimental manufacture was begun in October, 1916, but many difficulties were encountered in evolving a satisfactory type, and it was not until the beginning of 1918 that sufficient material had been collected to admit of large scale operations. From July onwards these attacks resulted in the enemy countries in increasing panic, which was enhanced by the complete secrecy which had been observed in preparation.[6]

The earliest kinds of incendiary bomb were petrol bombs of two types, large and small, composed of cases of tin and copper spinning containing petrol. At the end of 1914 other types in use

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[1] HIST. REC./R/1000/97.

[2] A modified 520-lb. light case design was also prepared by the Aircraft Armament Department, 11 June, 1918 (Superintendent of Design, Stock No. 8091).

[3] Superintendent of Design, Stock No. 8091.

[4] HIST. REC./R/1310/3. The filling of this bomb was at first arranged to give a total weight of 1,650 lbs. It was shortly afterwards increased to 1,700, and finally to approximately 1,800 lbs. This variation was a concession to the lifting capacity of certain machines, but it was finally determined that they were capable of operating generally with the maximum weight. At 1,800 lbs. the charge was approximately 900 lbs.

[5] HIST. REC./R/1312/1.

[6] HIST. REC./H/1960/2.

were a 20-pounder filled with incendiary composition and powder, with a nose fuse, a second 20-pounder containing trotyl and petrol with Very cartridge and striker, and a 10-lb. bomb filled with carcass powder.[1] The petrol and powder bombs were obsolete by the middle of 1917, and the type principally manufactured during the autumn of 1916 and the first six months of 1917 was a 10-lb. bomb filled with carcass composition.[2] In 1916, just prior to the Somme offensive, methods for the destruction of kite balloons were urgently required, and a small 3½-lb. bomb was produced together with a special carrier which held 17 bombs. These were fitted with a time fuse to give a burst in the air, and although little success was obtained with them, they marked an important step in the development of design. A larger type weighing 40 lb. carried on the standard 4/20-lb. bomb carrier was then produced, but was soon afterwards rendered obsolete by the development of incendiary ammunition for the destruction of balloons. These bombs were therefore fitted with a nose fuse and used for smoke production, and occasionally for spotting or incendiary purposes, though not suitable for the latter.[3] A new 30-lb. thermit bomb was in the experimental stage in June 1917,[4] but it did not come up to expectations and was never produced in quantity.

The 'Baby' incendiary represented a new departure in incendiarism. It was first produced for naval use in 1916.[5] The filling factory at Roslin, where these bombs were dealt with, was built specially for this purpose under the personal direction of Commander Ranken.[6] The cartridges contained a charge of thermit which burnt with a very fierce flame, and after the flame subsided the white hot slag continued the incendiary action. After their release from the drum container the small bombs, weighing only 6½ oz., descended in showers with a large spread, and on impact further dispersed their cartridges over the target area. They were dropped from a height of about 3,000 ft., and attained their terminal velocity in a drop of about 2,500 ft. In the later designs they were capable of penetrating any normal roof covering. The cartridge burnt under water, and the flame broke surface in depths up to 2 ft. The bomb has been used with good effect for crop burning and destruction of forest land, but during the latter period of the war it was successfully used in a combined scheme with large H.E. bombs. The Handley Page (V. type) aeroplane was capable of carrying 16,000 of these bombs, and it was found that the maximum strategic, moral and material effect was obtained by dropping a 1,700 lb. high explosive bomb closely followed by thousands of 'Baby' incendiaries.

A still later development was the adoption of thermalloy, a thermit composition which can be moulded and used without a metal case, thus giving practically 100 per cent. efficiency. Bombs of this substance were experimented with at the end of 1917, when it was

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[1] *Ordnance Board Annual Report*, 1915.
[2] Hist. Rec./H/1610/16.
[3] Hist. Rec./H/1960/2.
[4] Hist. Rec./H/1610/16.
[5] Hist. Rec./H/1960/2.
[6] T.W./11317.

used as a substitute for carcass concrete in the carcass bomb case.[1] Later it was used without a case, this form being first produced about August, 1918. It embodied the components of the 20-lb. bomb, but was never used in actual warfare.[2] At the end of the war the incendiary types in existence were the 40-lb. phosphorus, 10-lb. carcass, the caseless bomb, and the 'Baby' incendiary.

Gas bombs for dropping from aircraft, though prepared, were not actually used in the war. It is probable that the Government concurred in the opinion expressed by the Controller of Munitions Design (October, 1917) that high explosive was more certain and destructive in its effect, and that the enemy's fear of gas from aerial bombs consisted largely of the fear of the unknown, and as such was better left undisturbed.[3] In July, 1917, the Chemical Advisory Committee had designed and were about to experiment with gas bombs, but were deterred from further research by a decision not to use this type. A change in policy was anticipated shortly after, and the technical branch of the Air Board prepared designs. In May, 1918, however, it was decided that gas bombs should be used only in retaliation for their use by the enemy. Arrangements were made for design and immediate production on demand, but they were never required.[4] Danger due to forced landings, which had to be considered in the design of all aerial bombs, was particularly serious in the case of gas-filled bombs, and was no doubt partly responsible for the decision not to use them, the proposal being that the gas should be contained in earthenware vessels.[5]

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[1] D.M.R.S./467 B.

[2] *Ibid.*; Superintendent of Design, Stock No. 8091; HIST. REC./H/1960/2.

[3] D.G.M.D./B/074.

[4] D.G.M.D./B/074; HIST. REC./R/1310/3.

[5] HIST. REC./R/1650/29.

CHAPTER II.

THE ADMINISTRATIVE PROBLEM.

I. Organisation for Design and Supply.

(*a*) Supply.

On the outbreak of war the few aerial bombs then in use by the naval and military branches of the Air Service were supplied respectively by the Admiralty and the Directorate of Military Aeronautics. The Director-General of Military Aeronautics was a member of the Army Council, and the Directorate was divided into three sections, of which MA.2 was responsible for the supply and inspection of material and aeronautical equipment generally for the Royal Flying Corps (Military Wing), as well as for invention and experiments. The Directorate was reorganised about 6 May, 1915, when MA.2 was considerably enlarged. Its duties included (*inter alia*) the supply of and estimates for aeronautical equipment and stores, armament and ammunition for aircraft, the consideration of technical questions relating to specification, modifications in design and technical consideration of tenders by contractors. Thus the arrangements for the supply of aerial bombs varied from the normal course of War Office procedure, which provided that the Contracts Section should carry out all negotiations with firms, receiving the necessary instructions from the military section concerned, for Section MA.2, the demanding authority, frequently, though not uniformly, negotiated contracts with the trade. Since aerial bombs were not classified as aviation stores they were never dealt with by the Contracts Section of the Directorate of Military Aeronautics,[1] but such arrangements for supply as were not made by MA.2 were conducted by 1A,[2] later A7, the Contracts Department of the Director of Artillery, under a requisition from MA2. In July, 1915, Section A7 was transferred to the Ministry of Munitions as PM2,[3] but MA2 continued to exercise the functions of a supply department[4] until its duties were transferred in April, 1916, to section AE1C, under the Deputy Assistant Director of Aircraft Equipment. The same supply arrangement continued, this department ordering from and issuing their own instructions to contractors, so that the activities of the Contracts Department were confined to confirming instructions to proceed, and obtaining quotations which they had no means of checking. Owing to the slowness of communication between the Ministry and the army

[1] 94/B/103.
[2] 121/Stores/549.
[3] In March, 1916, this section became PM3 (94/B/943).
[4] T.W. 5625.

aeronautical authorities at Adastral House, it frequently happened that the order was confirmed after delivery had been made, the military authorities having in the meantime either cancelled or modified their instructions.[1] At the same time, the orders were increasing in number, and the unsuitability of a contracts department for the supply of such munitions became apparent. The bombs were quite unlike any other stores dealt with by the section, and the firms employed were in nearly all cases different, while aircraft bombs, which were still at the experimental stage, called for more extended technical supervision than the contract officers could give.

On the other hand the organisation of the Trench Warfare Supply Department rendered it peculiarly suited to deal with stores of a novel and experimental nature, and aerial bombs were similar in many respects to other munitions dealt with by that department. It was therefore arranged on 4 August, 1916, that this department should take over the supply.[2] The transfer came at an opportune moment, as, owing to the cutting down of War Office requirements for trench mortar bombs, the department found itself with considerable surplus capacity in filling stations and staff for dealing with such work. Moreover, it was already in touch with the Department of Military Aeronautics through having placed at their disposal certain trench warfare storage accommodation at Newhaven. The supply was taken over by Section TW3, under Mr. W. A. Tanner. From this time requisitions were made by the military branch in the normal way through the Director of Munition Requirements and Statistics, and the latter arranged with TW3 for supply.

The bombs dealt with by the Trench Warfare Supply Department were those for land service only, the Admiralty retaining at this date entire responsibility for those used by the Royal Naval Air Service. Early in 1917, however, when the demand for bombs for both services was rapidly increasing, it became apparent that there was much overlapping because the supply for the two services was arranged by different authorities, and that the only way to secure the necessary supplies was to standardise design, specification, and inspection for both services. Several types of bomb were almost identical for the two services, and in the case of the 20-lb. Hale and 112-lb. bomb the same firm was providing the army and the navy with the same bomb at different prices. In another case the army had a large surplus store, while the supplies of the navy were not sufficient to meet their requirements.[3] In May, 1917, the Admiralty were in the market for 230-lb. bombs, exactly similar to those provided by TW3 for the army, while at the same time a firm employed by the Trench Warfare Supply Department could, by securing a large order have offered a reduction in the price of from 10s. to 15s. per bomb. This case was an illustration of the advantages to be gained by the supply of all aerial bombs being placed under one department. The main obstacle to such an arrangement

[1] HIST. REC./R/1660/7.
[2] HIST. REC./R/1660/7.
[3] D.M.R.S./467 B.

was the unwillingness of the Admiralty to depute to any other authority the responsibility for the supply of bombs carried on board ship or stored in naval stores. In August, 1917, however, it became imperative to use every available means of economising and hastening supply. The rapid development of aircraft for war purposes[1] necessitated a greatly increased programme for bombs, and there seemed a danger that the production of aircraft would outstrip that of bombs.

In September, 1917, it was agreed that all bombs used by the Royal Naval Air Service for military operations not involving stowage on board H.M. ships, should be obtained through the Ministry of Munitions. The Admiralty retained complete control over those intended for use in submarine attack (all light-cased bombs), but to provide for the possibility of military operations being conducted by the Royal Naval Air Service machines using ships as a base, a sufficient stock of heavy-cased bombs were to be obtained by the Admiralty and manufactured under naval service inspection to designs supplied by the air services in consultation with the Ministry of Munitions. These bombs were to be held as a reserve in Royal Naval Ordnance Depôts. This arrangement ensured that all bombs used in France should be made to one design and specification.[2]

This unification of the supplying authorities was accompanied by unification of the demanding authorities. The naval branch of the service had previously indented on the Director of Naval Ordnance and the military branch on the Deputy Assistant Director of Aircraft Equipment, but the attention of the Air Board was now drawn to the necessity of establishing one responsible authority through which all demands should be received by the supply department. As the result of a meeting called on 13 August, 1917, by Sir William Weir, to consider the programme of supply of aerial bombs, a Bomb Committee of the Air Board was formed to deal with all matters relating to requirements and research upon aerial bombs.

This Committee, with Captain the Hon. A. Stopford, R.N., as chairman, and Lieut.-Colonel Romanes as secretary, contained representatives of the Royal Naval Air Service, the Royal Flying Corps, the Admiralty, Air Board and Ministry of Munitions. It was divided into six sub-committees dealing respectively with Requirements, Design, Production, Testing, Gears and Sights, of the first three of which the Director of TW.3 was a member, in order that he might be in touch at the initial stages with all questions affecting supply.

The Air Board (later the Air Council) was the authority for the general policy relating to aircraft bombs, *i.e.*, the number and sizes of bombs required, but all details of research and the numbers of each type were left to the Bomb Committee to arrange.[3] Later the Aircraft Armament Department became part of the Department of Aircraft Production, and requisitions reached the Requirements and Statistics

[1] In addition to increased numbers of aeroplanes, a new system of bomb carriers increased the possible expenditure of bombs by 400 to 500 per cent. D.M.R.S./467 B.

[2] D.M.R.S./467 B.

[3] D.M.R.S./467 B.

Department through that department. Section TW.3 of the Trench Warfare Supply Department was subdivided at the end of 1917, and TW.8 was created to deal solely with aerial bombs, Mr. Tanner remaining at its head. When the Trench Warfare Supply Department was disbanded in June, 1918, the Aerial Bomb Section was transferred under the same director to the Gun Ammunition Department and became known as AM.15, retaining special facilities for direct communication with the research and design authority and with contractors.

(*b*) RESEARCH AND DESIGN.

Designs for most of the bombs of the early types were prepared at the Royal Laboratory, Woolwich, and approval for land and naval service was given by the Director of Naval Ordnance and the Director of Artillery respectively.[1] The only aerial bombs in British service designed by other than the naval and military authorities were the Hale bombs, 10-lb., 20-lb., and 100-lb. The Director of the Air Department for the navy and the Royal Aircraft Factory for the army also produced designs and were consulted as to those designed at Woolwich.[2] Certain experiments relating to the efficiency of bombs were carried out by the Superintendent of Experiments at Shoeburyness, but dropping tests from aircraft took place at Grain and Orfordness, the experimental stations respectively of the Naval and Military Wings. When in December, 1915, the Design Department of the Ministry of Munitions was formed, research became the joint work of the Design Department of the Ministry and the military aeronautical authorities, the final approval resting with the Director General of Munitions Design.[3] When in August, 1916, aerial bombs became a trench warfare store, the Trench Warfare Research Department, under General Jackson, had become amalgamated with the Design Department of the Ministry, and some uncertainty seems to have existed as to the responsibility for them. General Jackson, writing in March, 1917, declared that he did not know who was supposed to be carrying on research with regard to aerial bombs, but stated that he had several times been asked to design them.[4] It was thought in March, 1917, that some special arrangement might be necessary, and a small committee was suggested on the lines of the Trench Warfare Committee, representing the Director of Naval Ordnance, the Air Board and the Director-General of Munitions Design, to deal solely and finally with the patterns and inspection of aerial bombs.[5] This plan was not adopted, and in practice the Air Board considered it necessary that the air services should initiate designs, as the suitability of the bomb for use in automatic droppers, and their safety in carriage on an aeroplane, were primary considerations.[6]

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[1] *Ordnance Board Annual Report,* 1915.

[2] *Ibid.*

[3] D.M.R.S./467 B.

[4] HIST. REC./R/1600/6.

[5] D.M.R.S./467 B.

[6] D.M.R.S./467 B; D.G.M.D./B/074. At the same time the Air Board welcomed plans put forward by the Design Branch of the Ministry of Munitions.

When the supply of bombs for both services was taken over by the Ministry a definite procedure with regard to research as between the air services and the Ministry was adopted. The air service concerned forwarded to the Munitions Design Department a statement of the requirements to be met and such details of the nature, dimensions, weight, etc., of the proposed store as might be available, together with drawings. The Design Department then consulted the supply and inspection departments concerned in order that the design should be scrutinised from the supply point of view, and if there was agreement stores for trial were arranged. As before, trials as regards efficiency were carried out by the air service concerned, the ultimate decision being with the Air Board, while the Munitions Design Department carried out investigations to determine the suitability of the store as regards safety in use, storage and transport. When all details had been settled and the Director of Naval Ordnance's concurrence in approval obtained, the drawing was sealed by the Design Department.[1] On the formation of the Bomb Committee, that body became responsible to the Air Board for researching in aerial bombs, and shortly afterwards (October, 1917) the evolution of the Chemical Warfare and Trench Warfare Design Departments secured the establishment within the Ministry of Munitions of separate design authorities coterminous with trench warfare supply.[2] This arrangement, together with the close co-operation between the Aerial Bomb Section (Trench Warfare) and the Bomb Committee, facilitated consideration of supply conditions in evolving design—an important point, since the utmost economy in raw materials was essential—and made it possible for supply officers to gain intimate knowledge of the behaviour of the stores in use. From this time drawings were discussed by the Bomb Committee and submitted for approval to the Controller of Munitions Design, who consulted the supply and inspection departments before final approval.[3] It was found that this arrangement worked well and quickly. In the case of one particular bomb which was required urgently, the final design was submitted within 10 days and full supplies were being received from manufacturers within six weeks from the date on which the preliminary design was discussed at the Bomb Committee meeting.[4] Drawings and specifications for the early types of R.L. bombs were issued by the Chief Inspector, Woolwich, and for bombs designed at the Royal Aircraft Establishment by the Secretary, R.A.E. Under the later arrangement information drawings were prepared by the department initiating the design and the final drawing by the Superintendent of Design (Trench Warfare) and officers of the department of the Controller of Munitions Design. The drawing after approval was sealed by the Director of Inspection, Trench Warfare, at the Inspection Department, Woolwich.

(c) Inspection.

The inspection of aerial bombs for land service was carried out partly by the Aeronautical Inspection Department and partly by

[1] D.M.R.S./467 B.
[2] Hist. Rec./H/1600/6.
[3] D.M.R.S./467 B 1.
[4] Hist. Rec./R/1310/3.

the Chief Inspector, Woolwich,[1] those for naval service being inspected by the Chief Inspector of Naval Ordnance. Towards the end of 1915, when the production of aerial bombs was no longer confined to Woolwich, inspection was sometimes arranged at the works of the producing firms by representatives of Chief Inspector, Woolwich,[2] or for firms in the north of England inspection was done by the Inspector of Steel, Sheffield.[3] Otherwise inspection took place at Woolwich. This dual responsibility continued until the end of 1916, when the Divisional Inspector of Guns and Grenades became the inspection officer. Bonds were arranged at various centres to facilitate inspection.[4] From April, 1916, onward the Trench Warfare Supply Department had urged separate treatment for trench warfare stores in relation to inspection, as well as design and proof, on account of their experimental nature, and in October, 1917, the directorate for inspection of trench warfare stores was created. Aerial bombs were from that time inspected by the Director of Inspection, Trench Warfare, and all questions relating to specifications and the supply of gauges were dealt with by that directorate.

II. Programme.

(a) UNCERTAINTY OF EARLY DEMAND.

In the first months of the war there was no specific or uniform demand for aerial bombs. The number of machines available and their bomb-carrying capacity were practically unknown quantities, and the adoption of any definite bombing policy was impossible. Supplies had to be arranged to meet intermittent demands from the Front. Towards the middle of 1915 the 20-lb., 100-lb., and 112-lb. bombs had been adopted as the armament for land machines of that time, and a specific though somewhat arbitrary monthly demand was issued for 5,000 20-lb. Hale, 750 100-lb. Hale, 750 100-lb. R.L., and 500 112-lb. From this time the problem of supply was simplified, though emergency measures had occasionally to be adopted to meet urgent demands necessitated by operations at the Front, and, owing to the fluctuations of actual expenditure, storage presented considerable difficulties. Emergency orders for experimental stores were frequently received from the Aircraft Armament officers independently of official demands by the Air Board or Bomb Committee. In September, 1916, the monthly demand for H.E. bombs was limited to 15,000 of the 20-lb. and 3,000 of the 112-lb. bomb,[5] though other types were still produced in small quantities to meet spot requirements.

An increase in the establishment of the Royal Flying Corps at about this time led to increased requirements, and before the end of

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[1] (Printed) *Weekly Report*, No. 58, VII. (9/9/16).
[2] 94/B/253.
[3] 94/B/588.
[4] T.W. 7484.
[5] D.G.M.D./B/418.

the month the demand for 20-lb. bombs had been doubled.[1] In October the requirement of 112-pdrs. was also doubled.[2] By the end of February, 1917, good supplies of 112-lb. bombs were coming forward from the trade, while supplies of the newly-designed 230-lb. bomb were quite inadequate to cover a demand for 2,000 per month, which was received at this time.[3] All the 230-lb. bombs were manufactured at the Ordnance Factory. The supply of components was short, but, the type being new, drawings had not been prepared, so that production could not be increased by an appeal to the trade. The Ordnance Factory therefore concentrated its capacity on the 230-pdr., and as soon as drawings were available contracts for this type were placed.[4] The army aeronautical authorities reduced the requirement of 112-lb. bombs to 3,000 per month; but stocks continued to accumulate, and in August it was decided to cancel contracts for this bomb and for the incendiary carcass of which also there were large stocks.[5] This decision was not acted upon, since the Air Board was then engaged in considering a new programme of aircraft production, which entailed a large increase in bomb supply.

(*b*) Provisional Programme, September, 1917.

The problem before the Air Board, in estimating requirements to meet this new programme, presented great difficulties owing to the absence of any satisfactory basis on which to calculate. The use of aeroplanes for bombing was still only in its infancy, and the number of types of machine designed for carrying bombs was very small, but the opinion was general that this form of warfare would undergo great developments, so that in adopting any programme a large margin of safety was essential.[6] In addition there was the uncertainty as to the date at which delivery of the machines might be expected, and as to the policy of bombing to be adopted. Weather conditions were bound to be a regulating factor in expenditure, while in view of the wide distribution of the squadrons a margin had to be allowed for stock at the various centres. The choice of types also had to be considered, and supply conditions demanded that their number should be kept as low as possible. A further unknown factor in the problem was the requirement of the United States for aerial bombs during the coming year.[7] It was also essential to remember that if expenditure did not come up to expectations, difficulties with regard to storage would ensue. This danger was partly met by a ruling that filling was to keep pace with expenditure, and not with the production of bomb bodies.[8]

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[1] (Printed) *Weekly Report*, No. 63, VII. (14/10/16).
[2] (Printed) *Weekly Report*, No. 61, VII. (30/9/16).
[3] *Ibid.*, No. 81, VII. (24/2/17); No. 83, VII. (10/3/17).
[4] *Ibid.*, No. 81, VII. (24/2/17); No. 84, VII. (17/3/17); D.M.R.S./467 B.
[5] D.M.R.S./467 B 1.
[6] D.M.R.S./467 B.
[7] This demand, stated as 28,000 20-lb., 188,000 50-lb., 100,000 112-lb., and 36,000 230-lb., was afterwards withdrawn, since the American aeroplane programme did not mature.
[8] D.M.R.S./467 B.

Four standard types of bomb were adopted as shown above, and a provisional figure for requirements was based on the number of machines and bombing squadrons approved for 1918, assuming that, if a vigorous policy of bombing were adopted, each machine might make four trips a week. This was afterwards thought to be too optimistic an assumption, and an average of two trips per week was adopted as a basis of calculation. The figures thus arrived at were as follows :—

20-lb.	20,000 per week.
50-lb.	8,000 ,,
112-lb.	7,000 ,,
230-lb. (or 250-lb.)	2,000 ,,

At the end of September the requirement of 112-lb. bombs was increased to 10,000 a week owing to a decision to use these chiefly at the Front, and in December it was again increased to 12,000 in view of the number of Handley Page machines using this type of armament.[1]

This programme was approved on 1 October, 1917. Steps had already been taken to obtain the necessary quantities of 20-lb. and 50-lb. bombs, but some delay was occasioned in the supply of the 112-lb. bomb on account of the adoption of cast iron for the case which necessitated a new design. With regard to the 230-lb. bomb, it had not then been decided whether this would be replaced by a new bomb of 250 lb. weight, then being designed, and arrangements for supply were temporarily suspended, pending settlement of this point. Eventually the new type was found to be unstable and had to be abandoned, and the 230-lb. was established as the standard bomb of this type.

At the end of 1917 the 6½ oz. 'Baby' incendiary was adopted by the Military Branch and a requirement of 1½ million was received by the Ministry. A demand was also made for a reserve of filled bombs ready for use overseas as follows[2] :—

20-lb.	100,000
50-lb.	35,000
112-lb.	50,000
230-lb.	10,000

In March, 1918, owing to fresh requirements for anti-submarine work and to the increased lifting power of the latest types of aeroplane, a demand arose for heavier types of bomb, and in addition to the previous requirement the Air Council asked for 200 250-lb.,[3] 250 520-lb. and 250 550 lb. per week.[4]

(c) REVISED PROGRAMME, JUNE, 1918.

The whole programme of aerial bomb requirements was revised in June. Experience had then been gained and it was found that the estimate of the rate of formation of new bombing squadrons had been too optimistic, and the expenditure of bombs had not been nearly as

[1] D.M.R.S./467 B.
[2] D.M.R.S./467 B.
[3] This bomb was previously used for naval service only.
[4] D.M.R.S./467 B. 1.

great as was expected. For the six months ending 31 March, 1918, the actual tonnage of bombs dropped amounted only to 785 tons[1] against a demand of 1,170 tons per week. The largest tonnage dropped in any one month was in March, 394 tons, *i.e.*, just under 100 tons per week.[2] The maximum expenditure of the different natures reported in any one week up to June was—

20-lb.	12,000 bombs.[3]
112-lb.	2,000 ,,
230-lb.	120 ,,

Stocks were accumulating rapidly, and it was expected that by the beginning of August the required reserve would have been reached. As from 1 August, 1918, the programme of supply was therefore reduced, but a new American demand for 20-lb. bombs was received in July, 1918, 85,000 being required for the navy and 263,000 for the army for the four months August to November.[4] This entailed further alterations in the programme of supply which was finally settled in August as follows[5] :—

Type of Bomb.	*Weekly Requirement.*	*Reserve filled.*
20-lb.	20,000 ..	150,000
50-lb.	2,500 ..	50,000
112-lb.	5,000 ..	50,000
230-lb.	750 ..	10,000
250-lb.	2,000 ..	10,000
520-lb.	250 ..	2,500
550-lb.	500 ..	3,000

The above programme was in force at the time of the Armistice, with the addition of a total demand of 1,000 S.N. bombs and 3½ million of the 'Baby' incendiary.[6] The 250-lb. bomb did not come forward until the end of September nor the 550-lb. until the end of October.

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1 This excluded 50-lb. bombs, regarding which there were no returns.
2 D.M.R.S./467 B. 1. 3 *Ibid.*
4 D.M.R.S./467/B. 1. 5 *Ibid.*
6 (Printed) *Weekly Report*, No. 167, Table III. (9/11/18).

CHAPTER III.

PRODUCTION, 1914–1918.

I. Introduction.

From the outset the supply of aerial bombs presented an entirely different problem to the supply of standard munitions of war. As in the case of most of the stores dealt with by the Trench Warfare Supply Department, the weapon was novel. It was not a case of developing existing means of production, but of creating new machinery. To do this while building up under war conditions huge capacity for other stores, entirely novel methods of procedure were needed. From the beginning both design and production were closely presided over by officers of the air services. Indeed, until August, 1916, the civilian element, usually connected with supply, was almost entirely absent. By that time a certain elementary degree of standardisation had been attained, and production by more usual methods was possible. Aerial bombs lent themselves in a marked degree to production by the methods employed by the Trench Warfare Supply Department. Their construction was not intricate, as compared with other weapons. Their components, though numerous, were of simple design, and could be produced with the tools usually to be found in small engineering works. The selection of contractors for the production of components by trench warfare engineers after an inspection of the works and machinery available saved much labour in unnecessary tool construction, as contracts for the components could be placed with the firms whose plant was best adapted for the purpose. Constant supervision over all contracts was specially necessary in the case of stores liable to frequent and sudden changes in design, as aerial bombs were throughout the war, owing to the fact that not only the bombs but the machines on which they were carried were in process of evolution. Carriers were undergoing constant improvement, methods of attachment had to be correspondingly altered : machines increased in lifting power—heavier types of bombs had to be evolved. Bombing from aeroplanes was a new method of warfare, and, as far as raiding enemy country is concerned, had not reached its final development at the time of the Armistice. Errors in decisions as to numbers or types required were righted only at the expense of some dislocation in production. Constant access by manufacturers to the advice of engineers in close touch with headquarters minimised these difficulties, and no serious delay in production took place owing to these causes. More serious were the delays due to shortage of material. Aircraft bombs developed comparatively late in the war, when shortage was being felt in material of all descriptions. Aerial bombs are not subject to a stress in any way comparable to that

borne by a shell case projected from a gun, and the lower grades of steel and cast iron which were adopted as the war went on, were found quite satisfactory as substitutes for the high-class material which was essential in the production of other munitions. The adoption of these other materials, however, entailed lengthy experiments which involved delay in production. This was specially pronounced in the case of the adoption of cast iron for the bodies of the 112-lb. and 50-lb. bombs. This delay was the less serious since good reserves of the 20-lb. and 112-lb. bombs had been stored up, and the machines D.H.9 designed to carry the 50-lb. bomb were equally well adapted for the 20-pdr.

The formation of the Bomb Committee was an important step towards efficiency of supply. Before its formation it had been found that requirements were not always made known by the air service in time for economical supply, since emergency methods had to be adopted.[1] The close co-operation between the committee and the supply officers was responsible for the fact that bomb supply throughout the war has always been equal to demand.[2]

II. Methods of Supply.

(*a*) Early Methods.

In the early months of the war practically the whole supply of aerial bombs was drawn from the Ordnance Factory, Woolwich. The only firm producing this store was the Cotton Powder Company, the monopolists of Hale's 10-lb., 20-lb. and 100-lb. bombs. Otherwise the manufacturing capacity of the country was entirely inexperienced, and since bombs were then in an elementary experimental stage, drawings to guide production could not be prepared. The Ordnance Factory was therefore the only possible source of supply at that time, but the demand soon outran its capacity, and in the early months of 1915 the factory was endeavouring to solve the problem of supply by sub-contracting for certain of the simpler types of bomb and components. Thus a fishing company[3] and firms of lighting engineers and founders were making petrol bombs in the spring of 1915, scientific instrument makers were providing strikers and delays, and a firm of oil engine makers were producing domes.[4] By June direct contracts for small petrol bombs were being made by the Directorate of Military Aeronautics, and orders for strikers, firing apparatus and fuses were placed in April and May, 1915, at various small engineering works.[5] It soon became necessary to create capacity outside the Ordnance Factory for bombs of a more intricate type, and provision having been made in regard to Hale's patent rights, outside engineering firms were

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[1] D.M.R.S./467 B. [2] Hist. Rec. R/1310/3. [3] 94/B/481.
[4] *Order and Supply List.* (Hist. Rec./R/5025.)
[5] *Order and Supply List.* 1 Aug., 1914—20 Sept., 1915.

encouraged to undertake 20-lb. bombs.[1] At first the trade showed some reluctance to enter upon this branch of work, and in May, 1915, of the eleven firms to whom forms of tender were issued, only two made returns, the rest excusing themselves on the ground that bombs were outside the capacity of their works.[2] Three months later, however, ten firms tendered for empty 20-lb., 100-lb., and 112-lb. H.E. bombs, including electrical engineers, acetylene welders, naval engineers, boiler makers and makers of sugar machinery.

The employment of small firms was continued and increased by the Ministry of Munitions, and when aerial bomb supply passed in 1916 to the Trench Warfâre Supply Department this practice fell into line with their systematic supply policy, and it was found that most of the firms employed in making aerial bombs and components were already producing other trench warfare stores.[3]

The Directorate of Military Aeronautics favoured the production by the contracting firm of the complete bomb, including filling and fusing, and in June, 1915, it was decided not to accept any bombs other than those of R.L. design that were not filled and fused by the company making them.[4] The number of firms capable of this was limited. The Thames Ammunition Works completed a contract for 20-lb. bombs, filled and fused, in October, 1915, and the Cotton Powder Company and Roburite and Ammonal, Ltd., dealt with complete 20- and 100-lb. bombs.[5] Later, efforts were made to find firms to undertake the filling of 100- and 112-lb. R.L. bombs and to fill fuses. After August, 1916, the Trench Warfare Supply Department undertook the filling in the filling factories of the Department, but the policy of contracting with one firm for the empty bomb complete with its components was continued. It was found, however, that this led to an inconvenient amount of sub-contracting, and failure of sub-contractors to keep their engagement was frequently put forward as an excuse by contractors for shortage in deliveries.

(*b*) GROUP MANUFACTURE AND ASSEMBLY SCHEMES.

The method of production by assembly under departmental control was not applied to aerial bombs until the end of 1917, but when in October, 1916, large contracts were being placed for 20-lb. bombs, it became evident that sub-contracting might become a source of danger.[6] Some four or five different metals entered into its

[1] The following clause was inserted in War Office Contracts. "The War Department takes full responsibility for infringement of patent rights, if any, in connection with the manufacture and supply of articles ordered under this contract, but any permission to manufacture to the order of the Secretary of State for War will not relieve the contractor of liability to penalty for infringement of patent rights should he manufacture for, or supply to, other buyers" (94/B/75).

[2] 94/B/75.

[3] HIST. REC./R/1660/7.

[4] 94/B/75.

[5] *Order and Supply List*, 1 Aug., 1914—20 Sept., 1915; D.G.M.D./B/418.

[6] T.W./7484, 7485.

composition, and the varied nature of the components made it impossible for any one firm to undertake the manufacture of every part.[1] The outside engineers at Birmingham, where a large number of these contracts were placed, suggested the wisdom of realising at the outset that a great deal of sub-contracting was bound to take place, and of controlling these sub-contracts from the start. They suggested that orders should be placed with main contractors who would be responsible for the machining of certain components and the assembly of the whole bomb, while the Department should place sub-contracts for certain other components, informing the contractors that these components would be supplied by these sub-contracting firms, but that the main contractor would be responsible for the viewing of them before their incorporation into the bomb. In the event of the rejection of the bomb or any part of it the main contractor would provide someone whose business it was to disassemble the bomb and rectify it. This policy was at once adopted by headquarters and carried out with few exceptions. It resulted in the saving of the large amount of labour and material which would undoubtedly have been absorbed in tool making and tool setting had the contracting firms attempted to deal directly with the components.[2] It had the additional advantage that the Department could prevent any sub-contracting which was likely to be prejudicial to existing contracts, and could arrange that sub-contracts were placed in the same area, thus economising transport. In some cases, however, where certain components were the special production of certain districts, economy demanded their production in those districts even when the main contractor was in other areas, *e.g.*, the steel springs, needles and vanes, brass needle holder, primer holder, nut releasing spindle and screws, and the aluminium vane and vane sleeve were the special products of the Birmingham and Manchester areas and were manufactured there for the Scotch engineers.[3] This method of sub-contracting was extended to all types of bombs, and was found to be very efficacious in speeding up production, for any manufacturer finding himself in a position to produce any part of the bomb was at once put into communication with firms likely to want such parts. In addition the outside engineers of the Trench Warfare Supply Department were in close touch with each firm supplying trench warfare stores and were often able to assist firms new to this branch of work, by arranging visits to others whose methods of production had been particularly successful.[4]

Towards the end of 1917 this policy was developed into the adoption of assembly schemes on a large scale under the control of the Trench Warfare Supply Department. The 336-lb. bomb had for some time been assembled at the filling station at Watford,[5] and a scheme was inaugurated in October, 1917, in the Birmingham area for the

[1] In August, 1917, Components, Ltd., had nine sub-contractors for different parts of the 20-lb. bomb. T.W./9695.

[2] T.W./7485. [3] T.W./7484. [4] T.W./7485.

[5] (Printed) *Weekly Report*, No. 58, VII. (9/9/16).

production of 20-lb. bombs, the assembling station being at Messrs. Components Works, Bournbrook. About the same time similar schemes were developed for the 50-lb. and 112-lb. bombs. The former was assembled in the Edinburgh area.[1] By the end of March, 1918, this method of supplying these three standard bombs was fully established, and it was largely due to this provision that supply was able to keep pace with the heavy demand to meet the German offensive in March and April, 1918. The 550-lb. and 250-lb. bombs were assembled at the National Projectile Factory, Lancaster.[2]

(c) SUPPLY OF COMPONENTS.

Bomb fuses and components were for the first months of the war provided by the Ordnance Factory, Woolwich. Early in 1915 it was found necessary to create supplies of these components from trade sources. Orders for detonators, strikers and fuses were placed with firms of electric telegraph engineers, gas engineers and scientific instrument makers. The 100-lb. and 112-lb. R.L. bombs required two fuses, for which orders were placed with the trade when the demand for these natures increased in August, 1915. In September, 1916, the requirement for exploders and detonators for the 112-lb. bomb was 9,450 per month, but the Ordnance Factory could fill only 1,250, and arrangements had to be made with the trade to fill the remainder.[3] The manufacture of aerial bomb fuses was comparatively simple, as compared with gun ammunition fuses, and since existing fuse capacity was at that time exhausted, new capacity had to be found. Forms of tender were sent to a great variety of manufacturers, *e.g.*, makers of electro-plate, motor and cycle parts, clocks and bells, watches, spooling machines, and metal screws. Some of the firms who undertook the work had been accustomed to fine work, such as magnetos and scientific instruments, but in other cases, *e.g.*, silversmiths and bedstead makers, the conversions of plant were more noteworthy.

Uniformity in the design of fuses had been aimed at from the beginning, but it was not until the end of 1917 that a type of nose fuse and exploder common to the 50-lb., 112-lb. and 230-lb. bombs and to converted 9·45-in. trench mortar bombs was evolved.[4]

(d) SHORTAGE OF RAW MATERIAL.

Until September, 1916, little difficulty was experienced in providing raw materials for aerial bombs. The increased demand after that date made the question of the supply of the necessary steel one of great difficulty. The tests applied to the material for these bombs was not as stringent as the usual Woolwich tests for cast steel for

[1] Conference of Trench Warfare Engineers, 28 October, 1917 (HIST. REC./R/1600/12).
[2] T.W./13030.
[3] (Printed) *Weekly Report*, No. 59, VII. (16/9/16).
[4] *Ibid.*, No. 124, XII. (5/1/18); D.M.R.S. 467 B.

gun parts, etc., but the specification required the steel to contain only ·2 to ·3 per cent of carbon and to have a minimum tensile strength of 26 tons per square inch. It was believed by many firms that steel of such low carbon content would hardly run in such a thin casting as the specification required, and though several firms in the Edinburgh and Leeds area were willing to produce a small number of bodies none could be found to tender in the Birmingham area. The James Cycle Co. approached 48 firms in Sheffield, Leeds and Glasgow for body castings without any success. Numerous firms were willing to produce the castings in malleable iron or semi-steel, but it was thought expedient to adhere to the original specification. The Scotch firms, however, were quite unable to produce the steel bodies in the necessary quantities; further, it was believed that some of the cases being passed at Woolwich were in reality steel alloy or malleable cast iron of a tough form, and to meet the demand for these bombs the specification was amended in February, 1917, to permit the use of forged steel, annealed steel alloy (semi-steel), and malleable iron castings, provided a minimum tensile strength of 16 tons per square inch was reached.[1] At the same time birch, ash and walnut were permitted as alternative materials for the tail. These modifications eased the situation with regard to this type of bomb, and contracts were easily placed. By May, 1917, it was reported from the Birmingham area, where the majority of these bombs were manufactured, that all the firms in that area were secure of their castings for the bomb bodies, and founders in that district were able to provide Scotch firms who were experiencing more difficulty in securing supplies. Production was also facilitated by the abandonment in November, 1916, of the Hale 20-lb. bomb, and the substitution for it of the 20-lb. Cooper, a much simpler and more economical type. The Hale bomb had always been recognised as unsatisfactory. It was of complicated design, and difficult to manufacture, but no satisfactory substitute had been found until that time.

The heavier bombs, for which until September, 1917, the demand was small, were still manufactured in cast steel. The 112-lb. bomb was produced almost entirely in the Leeds area, and though some difficulty was experienced in obtaining the steel castings, contracts were all placed by November, 1916.[2] The 230-lb. bomb was at this time manufactured and filled at the Ordnance Factory, and the small demand for 336-lb. bombs was met by the trade.

(*e*) CAST-IRON BOMBS.

The new programme of September, 1917, required a large increase in the supply of 20-lb., 112-lb., and 230-lb. bombs, and a new output of 8,000 per week of the 50-lb. bomb, and once more the situation with regard to material became acute. Difficulty was experienced in placing orders for 20-lb. bombs even in malleable iron, and in October the grade of material had once more to be reduced, a breaking strain test of

[1] T.W./7485.
[2] (Printed) *Weekly Report*, No. 68, VII. (18/11/16).

14 tons being substituted for 16.[1] Firms were encouraged to experiment with compounds requiring a minimum of hematite iron, and considerable success was obtained by several founders. One firm was, in November, carrying out experiments with a view to the utilisation of machine shop scrap, but they were at that time unable to modify the mixture they used, as a very high tensile strength was required for the greater part of their work, and their cupola capacity would not permit the production of the lower grade material which might have been used for the rest of the work. Another company was at that time actually using 25 per cent. steel scrap, and making investigations into other compounds. Several fairly satisfactory compounds were produced, but a tensile strength of even 14 tons was difficult to obtain.

Efforts were made to retain cast steel as the material for the bodies of the heavier bombs, but difficulties of supply were so great that in September provisional approval was given for a 112-lb. bomb of an amended design in cast iron. Early experiments with cast-iron bombs were not considered satisfactory, and an unsuccessful attempt was made in October to obtain priority for steel. Meantime, production in cast iron was temporarily abandoned. Further experiments were then made with segmented cases for the 50- and 112-lb. bombs, to secure complete fragmentation, the difficulty with the heavy cast-iron bomb being that it sometimes broke up before detonation was complete. Exhaustive experiments were carried out with the cases segmented laterally, longitudinally and both ways, but in every case better fragmentation was obtained with a bomb with as smooth a surface as possible, both inside and out.[2] In December production went forward on the 50-lb. bomb in cast iron. As regards the 112-lb., 2,500 of the total weekly demand of 7,500 were provided in cast steel and the remainder in cast iron.[3] Early in 1918 the increased tank programme entailed a still more drastic reduction in the use of cast steel for other purposes,[4] and it was then suggested that cast iron might be used in the manufacture of 230-lb. bombs. This was found to be impossible, since this type was used solely for anti-submarine work and to give a crater effect, and a thicker case would have reduced the explosive power.[5]

At the beginning of January, 1918, the deliveries of 230-lb. bombs were so short, partly owing to lack of material and partly to unexpected difficulties in manufacture, as to necessitate the use of converted 9·45-in. trench mortar bombs. This means of obviating the difficulty of supply had already been considered, trials having been made with a view to converting surplus 9·45-in. trench howitzer bombs in October, 1916,[6] and 4·5-in. and 6-in. H.E. shells a year later.[7]

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[1] T.W./7485. [2] T.W./11491 (Part II.).
[3] (Printed) *Weekly Report*, No. 121, XII. (8/12/17).
[4] D.M.R.S./467 B. [5] *Ibid.*
[6] (Printed) *Weekly Report*, No. 64, VII. (21/10/16).
[7] *Ibid.*, No. 113, IX. (13/10/17).

2-in. trench mortar bombs and the 58-mm. 'aerial torpedo' were also proposed as substitutes for aerial bombs, large quantities of these types being then in existence.[1] In January, 1918, sanction was given, subject to tests proving satisfactory, for the conversion of 100,000 2-in. trench mortar bombs. The results of tests of the accuracy of flight of these, which were spherical and had a tail piece, were not very satisfactory, but the 9·45-in., a bomb of cylindrical shape with vanes, made an excellent aerial bomb, and was adopted for use with the 230-lb. bomb carrier, its weight being approximately 160 lb.[2] The 2-in. trench mortar bombs were never adopted, because, even had tests given satisfactory results, their use for aerial bombs would not have been economical. A 112-lb. bomb cell was required to accommodate one such bomb (weighing about 60 lb.), and as they required vertical stowage the number of machines in which they could be used was limited. Moreover, because of their spherical shape, about 50 per cent. of the metal was embedded in the ground on detonation, and the proportion of the weight of the case giving useful shrapnel effect was small.[3]

The Air Ministry was repeatedly urged to reduce still further the demand for cast steel for aircraft bombs, but in the spring of 1918 bombing from aeroplanes was assuming great importance in the conduct of the war, and owing to the long flights undertaken and the danger to personnel and material entailed, it was felt that none but the best material should be used for heavy aircraft bombs, and all suggestions to construct them in cast iron were rejected. Experiments were, however, continued with semi-steel mixtures, and by August, 1918, excellent results were being obtained with alloys containing no hematite pig iron, and from 12½ per cent. to 15 per cent. only of steel scrap. High degrees of tensile strength, toughness and ductility were obtained, and it was believed that cast steel might be entirely eliminated in the manufacture of bombs.[4] Contracts for 112-lb. bombs in this metal (80 per cent. cast iron, 20 per cent. steel) of tensile strength 14 tons were being placed early in November, 1918.[5]

In the Birmingham area annealing was found to be a difficulty in connection with the production of the 20-lb. bomb. The Hope Works, Walsall, which supplied bodies to many firms in the district, had not sufficient oven capacity for their whole output, and were obliged to get assistance in annealing from outside firms.[6] In March, 1918, the specification was once more altered to overcome this difficulty, and unannealed semi-steel was permitted as an alternative material.[7] The cast steel bodies for the 550-lb. bombs were unannealed, as they were found to machine without difficulty in that state.[8]

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[1] D.M.R.S./467 B. 1. (Printed) *Weekly Report*, No. 123, XII. (29/12/17).

[2] Details of Aerial Bombs. (Printed) *Weekly Report*, No. 130, XI. (16/2/18); No. 131, XI. (23/2/18).

[3] D.M.R.S./467 B. 1.

[4] T.W./11491 (Part 2).

[5] *Ibid.*

[6] T.W./7485.

[7] T.W./9695.

[8] T.W./12786.

(f) Modifications in Design to Aid Contractors.

In addition to these modifications in design, necessitated by supply considerations, changes were sometimes approved with a view to aiding individual contractors. In the summer of 1917 a contract with a firm of cycle makers for 230-lb. bombs was very much in arrears, and to assist the firm, one of whose difficulties was the cast steel nose of the bomb, approval was given for making the nose in forged steel, while for the steel central tube McDougall's butt welded tube was permitted as a substitute for solid-drawn tube.[1] At the beginning of 1918 the central tube became a source of difficulty to other contractors, and the position was relieved by the sanction of increased tolerances, which allowed the use of lap-welded instead of cold-drawn tube.[2] A good many small concessions as to finish were made to contractors for the 20-lb. Cooper bomb in the spring of 1917, since it was found that production of this bomb was a matter of considerably greater difficulty than had been anticipated.[3]

When the 520- and 550-lb. bombs were first designed, in the spring of 1918, some delay in production was caused by alterations in the design made for the ultimate purpose of facilitating manufacture.[4]

(g) Arrangements for Filling.

At first the filling of all bombs and fuses, except the Hale 20-lb. and 100-lb. bomb, was carried out at Woolwich. As the output of bombs increased, the filling capacity of Woolwich became exhausted, and by the autumn of 1915 empty bombs were accumulating at the depots, with which the Ordnance Factory was quite incapable of dealing. Firms were asked to store their empty bombs while steps were taken to deal with the situation. The heavy 550-lb. bombs were a source of special difficulty owing to their bulk. Deliveries were due at the rate of 80 per week, and the filling capacity of the Ordnance Factory was only 150 per month. Arrangements were therefore made with the producing firm to regulate deliveries according to filling capacity, while they stored the remainder, and negotiations were entered into with the Explosives Loading Company to fill these bombs at Faversham.[5]

Other firms were sought, capable of dealing with the filling of the smaller Hale bombs and also of the R.L. 100-lb. and 112-lb. bombs. Two firms were found to deal with the 20-lb. bombs, but great difficulty was at first found in providing them with tetryl for the exploders.[6] In order to economise T.N.T. and to make use of capacity for filling, other than the melt plant at the Ordnance Factory, ammonal

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[1] T.W./7485.

[2] (Printed) *Weekly Report*, No. 131, XI. (23/2/18).

[3] T.W./7484.

[4] D.M.R.S./467 B. 1.

[5] 94/B/103.

[6] 94/C/1130; 94/B/75.

was used as a filling, and was found so successful that it was adopted as the normal filling for this type.[1]

The Filling Station Section of the Trench Warfare Supply Department gradually took over the control of filling for aerial bombs after August, 1916.[2] In October the Ordnance Factory was filling 1,500 112-lb. bombs per month, while 800 were filled at the Trench Warfare Factory, Watford, No. 2. In November the Ordnance Factory filled all the 585-lb., 16-lb., and 3·45-in. incendiary, and a few 112-lb. and 10-lb. incendiary carcass. The remainder were dealt with at the Trench Warfare National Filling Factories,[3] which had been built to handle ammonal. By the middle of 1917 the only land service bombs filled at Woolwich were the 230-pdrs.[4]

In September, 1916, ammonal had been adopted for the filling of 112-lb. bombs as an emergency measure in order to make use of the Trench Warfare filling plant, for 5,000 of these bombs were required by the Expeditionary Force at very short notice.[5] Ammonal was subsequently abandoned in favor of amatol, on account of its large aluminium content, and sabulite was temporarily used as an emergency filling for 20-lb. bombs, but was considered unsatisfactory. Alumatol, a similar mixture containing less aluminium, was approved for the 20-lb. Hale bomb and the 112-lb. in October, 1916,[6] and used for a short time only.

The position in June, 1917, was that the filling of aircraft bombs for which amatol 80/20 was used was carried out at Watford, while the Ordnance Factory was still engaged on melt filling with 40/60 amatol, which was still used for the 230-lb. bomb.[7] Three months later, when the demand for heavier bombs was greatly increased, amatol 80/20 was proposed as a filling for them also. The density of this filling is somewhat lower than that of 40/60 amatol, and it was thought that some modifications might have to be made in this case, owing to the slighter support given by the filling. Amatol 80/20 had been approved before January, 1918.

The filling adopted for the S.N. 1,700-lb. bomb was amatol 70/30, mixed to a density of 1·45. Experiments had been made with pure trotyl, amatol 40/60, and amatol 80/20, but 70/30 was found so satisfactory that it was contemplated in August, 1918, as the standard filling for all heavy type bombs, alternatively with 60/40 or 80/20, thus relieving the demand for 40/60 filling, which was still carried out exclusively at Woolwich.[8]

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1 94/B/522 ; D.G.M.D./B/418.

2 Hist. Rec./H/1600/6.

3 (Printed) *Weekly Report*, No. 67, VII. (11/11/16).

4 D.M.R.S. 467 B.

5 D.G.M.D./B/418.

6 *Ibid.*

7 Hist. Rec./H/1610/16.

8 D.M.R.S./467 B. 1.

III. Review of Output.

No complete figures of output of aerial bombs prior to August, 1917, can be given, owing to the diversity of authorities responsible for supply. Even after this time figures are incomplete, as they do not include those supplied by the Admiralty for the use of the Fleet.

Prior to August, 1916, the output of bombs was very small, for expenditure amounted only to a few tons a month in submarine attacks and isolated land operations or raids. From August to December, 1914, only 614 high explosive bombs were produced by the Ordnance Factory for land service, and the number of Hale bombs produced by the Cotton Powder Company during that time was negligible. The output of petrol bombs was larger, amounting to 1,299. Production did not materially increase until the third quarter of 1915. Woolwich output then increased rapidly, reaching a maximum in the spring of 1916, the production of bombs made by the trade and filled at Woolwich increasing proportionately. By the end of 1916 trade capacity had been organised, and bombs were coming forward in large quantities. During 1917 a remarkable increase in output took place. The average weekly production of completed bombs for the year ending October, 1916, was 1,900, and for the year ending October, 1917, 5,900, corresponding to tonnages of 81 and 207 respectively. An equally rapid average increase was maintained throughout 1918, the figure being 175,300 weekly, representing 1,705 tons of bombs.[1] It should, however, be pointed out that figures of output after September, 1917, include bombs for the Royal Naval Air Service, which were not included in the earlier returns. The increase in 1918 was again most marked in the spring.[2] The assembly schemes of manufacture were beginning to be effective, and production was being pressed forward to accumulate the stocks required by the Air Council. Bombs were, in fact, coming along in advance of the aeroplanes, and expenditure up to March, 1918, was insignificant compared with production.[3] Demands in September, 1917, both by the Air Board and the American Government, had been on the high side, and the specified reserve of 20-lb. bombs had been reached by January, 1918. In addition, considerable contributions towards the reserve of 112-pdrs. and 230-pdrs. had been collected.[4] When, therefore, during the German offensive in March and April, the overseas demands were five times the estimated requirement, stocks were not unduly depleted. They were reduced, but within two weeks the full war reserves had again been reached.[5] Bombing policy developed rapidly in 1918, and in August approximately 1,500 tons of explosive and incendiary bombs were expended.[6]

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[1] HIST. REC./R/1310/3.

[2] *Review of Munitions Output,* 1914-18.

[3] D.M.R.S./467 B. 1.

[4] *Ibid.*

[5] HIST. REC./R/1310/3.

[6] HIST. REC./H/1960/2.

Throughout the war output of the light bombs (16-lb. R.L., 20-lb. Hale and Cooper) was greatly in excess of that of the heavier natures.[1] The 20-lb. bomb was specially in demand in March and April, 1918, as it proved very effective against massed troops. It was however found that, owing to the fitting of the carrier, the bomb did not always function well when dropped from low heights, and special fittings were in course of development at the end of the war.[2] At the time of the Armistice there was a stock of 139,800 filled and 571,600 empty 20-lb. bombs; and at the end of the year 400,000 empty bombs, as well as 17,500 filled bombs, of the type were authorised for disposal.[3] There were also large stocks of 50-, 112-, and 230-lb. bombs at the Armistice, but of the heavier bombs and incendiary types there was no surplus.[4]

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[1] *Review of Munitions Output*, 1914-18.

[2] D.M.R.S./467B; HIST. REC./H./1960/2. When suspended vertically it took from 400 to 500 feet of fall to attain the correct position.

[3] (Printed) *Weekly Report*, No. 169, Table III. (23/11/18); HIST. REC./R/1312/1.

[4] *Ibid.*

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VOLUME XII.

THE SUPPLY OF MUNITIONS.

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CHAPTER I.

EARLY PROJECTS.[1]

I. Introduction.

(a) Mother Tank.

The tanks which first took the field in the Battle of the Somme, 15 September, 1916, were all of one design, save for a distinction in armament, whereby they were styled "male" or "female." The pattern or "Mother Tank" to which they were built had been completed in the previous January. Mother Tank was not herself an actual fighting vehicle, her casing being of mild steel only; but in other respects she fully conformed to the specification adopted in the manufacture of her armoured progeny, who possessed, however, a protective shell varying in kind and thickness with the vulnerability of their parts.

Mother Tank was a completely covered car, 31 ft. by 8 ft., and weighed, fully armed and equipped, 28 tons 8 cwt. She was rhomboidal in shape with blunted ends to enable her to surmount obstacles in front or in the rear. She could run either way at a speed varying between three-quarters and four miles an hour. Her Foster-Daimler engines were of 105 h.p. She was propelled on two specially constructed caterpillar tracks, which completely encircled the body on either side and extended well beyond both ends. For steering in small turns she had an elastic tail of two wheels which also absorbed the shock in passing over banks. Quick turns were effected by throwing one or other track out of gear. On either side her guns were mounted within the circuit of the tracks in detachable sponsons which added five feet and a half to her width. Intended as a cross-country vehicle, she could traverse with ease a 9-ft. gap after climbing a perpendicular parapet of 4 ft. 6 in. She could break her way through wire entanglements, scramble across shell-craters and travel on hard roads or over water-logged marshes, provided the mud and water were of moderate depth and extent.

(b) Anticipations.

Mother Tank was the result of a definite concerted effort to meet by the development of a "landship" the specific conditions which prevailed on the Western front shortly after the outbreak of war. The idea of a mechanically propelled landship was not in itself novel. James Cowen, "social, medical and political reformer," had taken

[1] Based mainly upon copies of documents among Mr. Churchill's papers (Hist. Rec./R/1940/13), upon the relevant Admiralty papers (C.P.170761/15, 170762/15, and copies in Hist. Rec. R/1940/22) and War Office papers (121/Stores/1322, 2531, 7330; 84/C/4715) and upon evidence before the Tank (Awards) Committee (M.I.D./R/1525, 3209, 3250).

out provisional protection for a "locomotive land battery fitted with scythes to mow down infantry" in 1855, and had urged upon Lord Palmerston the adoption of his device. In 1903 Mr. H. G. Wells had visualised "Land Ironclads" as "something between a big blockhouse and a giant's dish-cover . . . from 80 to 100 ft. long, moving up gentle slopes at six miles an hour and crossing 30 ft. trenches by means of Diplock pedrails." The military value of armoured cars on wheels had been tested in the South African War. One subsequent proposal, at least, suggesting an armoured vehicle or "Land Ironclad" was submitted to the First Lord of the Admiralty in November, 1911. Another proposal, recorded in a private letter of 16 October, 1914, was for a "travelling motor fortification and charging device" constructed with a front and rear plough for charging earthworks, the whole to "skip over" trenches 10 or 12 ft. wide.

If the basic idea of a mobile fort was not itself a novelty neither was the mode of traction by means of caterpillar feet unfamiliar. The caterpillar form of traction was comparatively well known at the outbreak of war, particularly in the United States, where caterpillar vehicles of the Holt and other types were manufactured for agricultural purposes. British production was then limited to the Diplock Pedrail Company and to the firm of William Foster & Company, Lincoln, where for some years the "Centipede" type of caterpillar vehicle steered by brakes holding one or other track had been built for export on behalf of Richard Hornsby & Sons, of Grantham, inventors of caterpillar traction. The use of caterpillar traction for military purposes had already been considered in 1908, when a Hornsby chain track tractor had taken part with another machine in the Royal Review at Aldershot. Various authorities received a considerable number of proposals for converting caterpillar tractors to military purposes during 1914. Thus the application of caterpillar traction to armoured cars was suggested (22 August, 1914) to Flight-Commander Delacombe by Lieutenant R. F. Macfie, and by Lieutenant B. J. F. Bentley to Lord Kitchener's military secretary, Colonel Fitzgerald, in the following October. Orders for Holt caterpillars for use as tractors were placed through Balfour Williamson & Company in the latter half of the year.

This list is by no means exhaustive. But it would be impracticable to enumerate exhaustively the schemes for protected vehicles capable of crossing the firing zone and entrenchments of the new warfare which individuals had thought out independently before the first tank was built. In this chapter it is proposed to deal in detail only with suggestions which directly influenced or stimulated the administrative activities leading up to the construction of "Mother Tank" and her approval as an engine of war in the British Service.

II. Proposals formulated in January, 1915.

Definite recommendations for an armoured vehicle carrying guns or men or both and serving as a weapon of offence emanated simultaneously from several quarters in January, 1915. It is at

this moment that the quest first received formal departmental recognition, and that the official machinery was definitely set in motion. It is therefore a convenient point at which to begin the narrative of events leading to the evolution of the first tank.

Each of the proposals now to be considered was the result of previous reflection or investigation and belongs to that larger group of suggestive foreshadowings which heralded the development of the new idea; but each had a practical bearing upon the course of subsequent activities and consequently a quite special importance. Each suggestion specified caterpillar traction as an obvious method of crossing open country and particularly trenches. In each case the new engine was recommended as a means of meeting the conditions of siege warfare which had prevailed on the Western front since the Battle of the Aisne in the previous September.

The one scheme was formulated on 5 January, 1915, by Mr. Winston Churchill, then First Lord of the Admiralty. In a letter[1] addressed to the Prime Minister, *apropos* of suggestions recently made by Colonel Hankey[2], he stated that—

"It would be quite easy in a short time to fit up a number of steam tractors with small armoured shelters, in which men and machine guns could be placed, which would be bullet-proof. Used at night they would not be affected by artillery fire to any extent. The caterpillar system would enable trenches to be crossed quite easily and the weight of the machine would destroy all wire entanglements. Forty or fifty of these machines, prepared secretly and brought into positions at nightfall, could advance quite certainly into the enemy's trenches, smashing away all the obstructions and sweeping the trenches with their machine gun fire and with grenades thrown out of the top. They would then make so many *points d'appui* for the British supporting infantry to rush forward and rally on them. They can then move forward to attack the second line of trenches. The cost would be small. If the experiment did not answer what harm would be done? An obvious measure of prudence would have been to start something like this two months ago. It should certainly be done now."

The other proposals came from three officers who had devoted thought during the previous months to the possibility of a "land cruiser." The one, Lieut.-Colonel E. D. Swinton, assistant secretary to the Committee of Imperial Defence, returning on three days' leave from France, where he had been acting as official "Eye-Witness," had in October, 1914, consulted the other two, Lieut.-Colonel M. P. A. Hankey, secretary to the Committee of Imperial Defence, and Captain T. G. Tulloch of the Chilworth Powder Company, an expert in ballistics and high explosives who had served in the Experimental Branch at Woolwich Arsenal.

Each of these officers put forward a specific recommendation in January, 1915. On the first day of the month, Colonel Hankey circulated to the Committee of Imperial Defence a memorandum[2]

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[1] Appendix II. [2] Appendix I.

(dated 28 December, 1914) suggesting among other mechanical devices for trench-taking the use of heavy rollers driven from behind by engines on caterpillar tractors, so as to crush wire by sheer weight, give some cover to men creeping behind, and support an advance with machine gun fire.

Colonel Swinton, again returning to England on four days' leave, called at the War Office and saw Major-General Sir George Scott-Moncrieff, Director of Fortifications and Works, the most appropriate person to consider mechanical contrivances for trench warfare, 4 January, 1915. Colonel Swinton urged the possibility of using "an armoured motor car with caterpillar traction manned by a small crew sufficient to work two machine guns for the purpose of countering the German machine guns." At the same time he pointed out the grave need for some means of holding captured enemy trenches against enfilading machine-gun fire.

Colonel Swinton arranged at the same time that in his own absence Captain Tulloch should lay the details of the project before General Scott-Moncrieff. This was done in the form of a memorandum[1] on the "Landship," which Captain Tulloch forwarded, 19 January, 1915, to General Scott-Moncrieff through Colonel Louis G. Jackson, who was then working in the Directorate of Fortification and Works upon questions touching trench warfare, and had undertaken (5 January) to urge the matter forward. The main proposal was stated as follows :—"If a means could be found for mounting either ordnance and/or machine guns on a carriage which could move across country, and to the passage of which neither barbed wire nor trenches nor embankments (within such reasonable dimensions as might be expected) offer any hindrance, it would appear that the provision of such a fleet of carriers would confer upon that force which first made use of them, and provided they came as a surprise to the enemy, a power of offensive of vast potentialities, for it would enable the attacker to place himself athwart and enfilade the enemy's trenches, tearing through the barbed wire entanglements on the way, thus opening a road for the supporting infantry, and even eventually for the cavalry. The point of attack would be unknown beforehand to the enemy, thus making special defensive provisions very difficult. . . So far as the carriage is concerned, there seems to be only one principle which can be employed, namely, that the carriage should lay its own road-bed on the principle of the Hornsby-Akroyd caterpillar type which has subsequently been improved upon in the Holt caterpillar."

The memorandum discussed in detail the relative merits of the 'land cruiser' and the lighter 'land destroyer.' "The 'land cruiser' would be fitted with quick-firing guns, searchlights and machine guns, and would carry such thicknesses of armour as would protect the crew from anything but the effects of a high explosive from a gun or howitzer above ordinary field gun size. . . . The 'land destroyer'

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[1] Appendix III.

consisting of a very much lighter carrier and mounting two or three machine guns only. . . . might be quite effective for simply turning the personnel out of the trench, but on the first hit from a field gun it would be put out of action."

Before the proposals of January, 1915, both Colonel Swinton and Captain Tulloch had given long consideration to the advantage of a landship as a defence against the increased use of machine guns. Captain Tulloch had sketched out drawings[1] of an engine on caterpillar tracks towards the end of 1911, when a visit to Berlin had brought to his knowledge the tremendous increase in machine gun manufacture for the German Government. The sketches made at this time showed articulated vehicles consisting of linked Hornsby-Akroyd tractors, carrying six 12-pounder Q.F. guns, 12 machine guns, and a hundred men, and protected by armour. Even before this time Captain Tulloch had already considered the practicability of mounting shields and armament on this type of caterpillar, when it was exhibited at the Agricultural Hall, 1906-1908.

Colonel Swinton's attention had been drawn to the capacities of Holt caterpillar tractors in the summer of 1914. Mr. Hugh F. Marriott, an engineering specialist, had then described to him the achievements of a Holt tractor with special detachable lugs, the capabilities of which had been demonstrated by M. Jules Schnerb at Westmalle, near Antwerp, 23 June, 1914. This machine was an adaptation for marshy land of the Holt tractor built for the soft sandy soil of California. At the demonstration it travelled over marshes, dragged a five-furrow plough through slimy mud and rank grass, and climbed a four-foot embankment.. In July, 1914, Colonel Swinton drew the attention of the Director of Mechanical Transport (General Landon) and the Director of Artillery (General Guthrie-Smith) to the capacities of this machine as a military tractor for cross-country purposes. He also brought the point to the notice of Admiral Slade, then occupied with the problem of transporting heavy pipes across the desert to the Persian oilfields. The need for protecting infantry in assault against machine guns used by the enemy in large numbers and with great skill was vividly impressed upon Colonel Swinton by direct observation in September, 1914. He then conceived that idea of improving the Holt caterpillar into a mobile, bullet-proof "machine-gun eater" which he discussed with Colonel Hankey and Captain Tulloch in the succeeding month. During the rest of the year 1914 he had pressed the matter in France and Colonel Hankey had taken it up at home, neither so far securing any definite official encouragement.

The problem of cross-country traction had been brought to Mr. Churchill's attention through the activities of the Armoured Car Section, R.N.A.S., established by him about 1 September, 1914, as a support to aeroplanes making forced landings in the Dunkirk area. The class of car employed developed rapidly under Commodore Murray F. Sueter, Director Air Department, from the first machines, which were improvised by bolting steel plate to the more vulnerable parts.

[1] *Penes* Major T. G. Tulloch.

Shortly after the fall of Antwerp (9 October) Commodore Sueter decided, in discussion with Lord Wimborne, Squadron-Commander W. Briggs, and Squadron-Commander T. G. Hetherington, to mount machine guns in a revolving turret with overhead protection. Heavier cars were subsequently devised by mounting 3-pdrs. on armoured motor-lorries. The organisation of the section into lighter and heavier squadrons was well advanced by mid-November; but its activities were checked by the destruction of roads by German cavalry patrols and by the extension of trench warfare to the coast in October, 1914. The development of a weapon to meet the conditions of trench warfare then became a subject of frequent discussion between Mr. Churchill and Commodore Sueter. Two other solutions of the problem had been considered by the First Lord before his proposals of 5 January. The one was the use of steel screens on wheels for the protection of advancing infantry. He had authorised the design and production of twenty such shields by the R.N.A.S.[1] early in December, and had discussed model steel screens with the Third Sea Lord, Admiral Sir F. C. T. Tudor, for many years an enthusiastic advocate of the use of armour protection on shore. The second project was to enable a heavy wheeled vehicle to cross a gap by means of a bridge of girders which it laid down before itself and hauled up after clearing the obstacle. This scheme had been brought to Mr. Churchill's notice in November, 1914, by Admiral Sir R. H. S. Bacon, of Coventry Ordnance Works, then under contract to the Admiralty for 15 in. howitzers with wheeled tractors for land service. The project was laid before Sir John French by Admiral Bacon at General Headquarters, France, and was officially submitted to Lord Kitchener at Mr. Churchill's suggestion.

III. Investigations under Mr. Churchill at the Admiralty, January-May, 1915.

(*a*) THE BRIDGING DEVICE.

Early in January, 1915, Admiral Bacon had attended at Lincoln trials of wheeled tractors for the 15 in. howitzers which Messrs. Foster & Co. were making under sub-contract to Coventry Ordnance Works. One of the engines under trial hauled a lorry over a portable bridge designed by Mr. W. Tritton, managing director of Messrs. Foster & Company. Thereupon, Admiral Bacon broached with Mr. Tritton the proposal to attach an automatic bridging device to an armoured tractor carrying guns. Models of the intended machine were shown to Mr. Churchill, who gave a provisional order for its production in some numbers. By Lord Kitchener's directions arrangements were also made on 12 January, 1915, for the trial of a tractor fitted with the device. Admiral Bacon was at work upon the design of the apparatus, 23 January, and expected to carry out trials at Lincoln about 15 February with an improvised 15 in. howitzer-tractor carrying weights to represent armoured towers. His departure to France early in

[1] Appendix II.

February in command of the 15 in. howitzers, however, took from the development of this design the energy due to his conviction of its utility. Meanwhile, other suggestions for the production of a landship, brought forward by Major T. G. Hetherington, gave promise of greater success. Accordingly, on Saturday, 20 February, Mr. Churchill gave verbal instructions to Mr. Tritton to cease work upon the bridging devices ordered for the Admiralty.

(*b*) MAJOR HETHERINGTON'S SUGGESTIONS FOR A LANDSHIP.

Experimental work upon methods of cross-country traction had been continued under the Air Department of the Admiralty during January and February, 1915. Mr. Churchill also instructed Commodore Sueter, 19 January, to carry out experiments in crushing a line of trenches by means of two steam-rollers linked together. While the bridging device was still under consideration, Squadron-Commander T. G. Hetherington submitted to Commodore Sueter a proposal for mounting a 12-pdr. gun on a large land battleship running on wheels. The Commodore then instructed him to investigate the suggestion in conjunction with Wing-Commander W. Briggs and Mr. Booth, a technical adviser to the Air Department. All available information concerning existing types of agricultural tractors was to be obtained for this purpose. About 17 February, Major Hetherington described his project to Mr. Churchill at a gathering at Grosvenor House. He visualised "land battleships of great size, crashing through woods and towns, trampling down trenches and other obstacles and even passing rivers." At the same time he described the advantage of the Diplock pedrail or caterpillar track as a means of cross-country traction, and arrangements were made for a demonstration of this type of caterpillar to take place, attempts having failed to procure Holt or Bullock caterpillars of American manufacture. Accordingly, a Diplock tractor, loaded with thirty hundredweight of bricks and intended for use in the Malay, was demonstrated at nine o'clock in the morning of 19 February on the Horse Guards Parade before Mr. Churchill, who was able to move the vehicle with one hand.

Commodore Sueter at the same time pointed out that the use of caterpillar traction would overcome the difficulties experienced with springs and tyres by the Armoured Car Section, would enable more armament and crew to be carried, and would eliminate the need for carrying planks for crossing ditches and holes, thus avoiding the exposure of the crew in laying their own bridges. The machine would be able to roll down wire. A blunted end, similar to that of a submarine, would aid it to get out of ditches.

In the meantime a rough specification was being prepared in the Air Department for "the new weapon . . . or cross-country armoured car . . . proposed by Flight-Commander Hetherington . . . with a view to providing forces operating on land with a method of breaking down the resistance of the enemy when he resorts to 'siege warfare.'" The machine would consist of a platform on three

wheels, the stern wheel being for steering. It would carry three turrets, each containing two 4 in. guns. It was estimated that the diameter of the wheels would be 40 ft., the total weight 300 tons, the length 100 ft., the height 46 ft. Its prime function would be to operate field guns or howitzers. These data were approximate only, since it was admitted that the department had not the technical knowledge properly applicable to the problem. Mr. Churchill was convinced that whereas the size and strength of the machine might be greatly varied, the chief difficulty to overcome was the mechanical problem of construction, which could be surmounted though it was very great. He instructed Major Hetherington to lay his proposals before the First Sea Lord, Lord Fisher, who authorised him to proceed if approval were obtained from the Director of Naval Construction, Mr. E. Tennyson d'Eyncourt. On 18 February, 1915, Mr. Churchill laid before Mr. d'Eyncourt the specification drawn up in the Air Department and appealed to him to lend the unique resources and experience of the Admiralty Constructive Departments to the solution of the problem, discussing the project with him upon several occasions and finally entrusting him with the responsibility for producing a design and for the expenditure on the early experimental machines.

(c) Formation and Work of the Admiralty Landships Committee (February-May, 1915).

On Saturday, 20 February, 1915, Mr. Churchill called Mr. d'Eyncourt, Colonel W. C. Dumble and Major Hetherington to confer with him in his room at the Admiralty on the proposals made by Major Hetherington. Mr. d'Eyncourt then agreed to preside over a small committee which should investigate the technical details of the project. This committee first met on the following Monday in Mr. d'Eyncourt's office. There were present Mr. d'Eyncourt, Major Hetherington and also Colonel Dumble, who brought into consultation Colonel R. E. Crompton, a well-known engineer who had served in the Crimean war and had been employed upon mechanical transport problems during the South African war.

At its first meeting, 22 February, 1915, the committee discussed at length the respective merits of large wheels and caterpillar tracks, the advantages of the latter being set out by Lieut. R. F. Macfie. Mr. d'Eyncourt advocated an attempt to produce a machine somewhat less ambitious than the giant landship proposed by the Air Department, as he did not at that time see his way to surmounting the mechanical difficulties involved in the larger project. The committee therefore recommended the manufacture of two 25-ton landships, which, if necessary, could be regarded as models for a larger design. Two working models had already been arrived at independently, both being almost identical in principle. The one would be a modification of one of the howitzer tractors under construction at Foster's works, Lincoln. The other would be fitted with caterpillar tracks of a type to be chosen by the committee. Both would carry fifty men together with machine guns and would be capable of negotiating trenches.

The next day application was made to the Road Board for the loan of Colonel Crompton's services as consulting engineer to the committee. Since 18 February he had been investigating the problem of a "trench-straddling engine" at the instigation of Colonel Dumble. By 22 February he had drawn up a scheme for "a self-moving armoured fort for the attack and destruction of enemy trenches." It would consist of a single platform partly armoured and mounted on 8 ft. wheels. It would carry fifty men with machine guns. The platform projected beyond the base so that the garrison could enter enemy trenches through openings in the floor of the overhanging bow. It was estimated that the fort could pass over 8 ft. trenches without bridging.

The committee's proposals for the manufacture of two 25-ton "models" were submitted to Mr. Churchill on 24 February, and he gave instructions for their execution "with all despatch." The committee held its second meeting on the day following, when the schemes for the two 25-ton "models" and the provisional design of a heavier machine were discussed by Mr. d'Eyncourt, Major Hetherington and Colonel Crompton. Arrangements were immediately made to proceed with the conversion of a wheeled tractor at Lincoln. Colonel Crompton visited Mr. Tritton on 26 February, 1915, and informed him of the main outline of the committee's scheme for a man-carrying fort. These differed somewhat from Mr. Tritton's own proposals, which were for two lightly-armed machines carrying two or four machine guns. The wheeled type of landship was again discussed with Mr. Tritton at Lincoln on 2 March, 1915, by Mr. Legros, President of the Institution of Automobile Engineers, who had been called in to assist Colonel Crompton. At this time, Mr. Tritton preferred wheels to caterpillar traction on the ground that barbed wire would jam the tracks and that excessive twisting stress would prohibit the safe mounting of platforms upon the firm's own type, the "Centipede" caterpillar tractor.

Active steps to develop the caterpillar model were taken by Colonel Crompton, in conjunction with representatives of the Diplock Pedrail Company during March, 1915, the pedrail type of caterpillar having been under Colonel Crompton's consideration in connection with military traction since October, 1914. At the third committee meeting, 5 March, the Director of Naval Contracts was represented by Mr. P. Dale Bussell, who thenceforward became a member of the committee. Definite arrangements were made for placing contracts on a cost plus percentage basis, and for dividing the work on the parts of the caterpillar model into four main contracts. Progress was reported on 9 March to Mr. Churchill, who gave instructions to "press on." It was ruled (13 March) that the cost of the machines should be assigned to the contracts section of the Admiralty vote for shipbuilding. Colonel Crompton entered into negotiations with Messrs. Fodens of Sandbach to undertake the main contract for construction of the caterpillar type of machine.

By 20 March, 1915, Colonel Crompton was in a position to show models of the two 25-ton landships. These were examined by Mr. d'Eyncourt and afterwards by the First Lord and the Third Sea Lord,

application being made for authority to buy three Rolls-Royce chassis and to proceed with the two landships. After discussion, it was proposed that manufacture of twelve of the pedrail type and six of the big wheel type should be put in hand. Mr. Churchill desired estimates of time and money, noting at the same time that the matter was "most urgent" and that special report should be made to himself in case of delay. The estimates were discussed at a meeting between Colonel Crompton, representatives of the Air Department, and Director of Contracts. The total cost of the eighteen machines, with equipment and workshop but without armament, was assessed at approximately £70,000. It was thought that the first pedrail landship could be completed in fourteen weeks, the first of the wheel type in twelve weeks. In view of these estimates, Mr. Churchill authorised the construction of the eighteen landships "with all despatch" (26 March), stating that on account of secrecy these instructions might be taken as full sanction. It was intended to produce an actual machine for trial before communicating with the War Office, so that the assent of military authorities to the proposal should be ensured. Steps were immediately taken to expedite construction of the eighteen landships, and on 26 March, 1915, telegraphic orders to proceed were sent to the contractors. Messrs. Fodens, of Sandbach, undertook the main work of building the twelve pedrail machines. The Rolls-Royce Company provided engines for these. McEwan, Pratt & Company, of Burton-on-Trent, were responsible for gearing, the Steel Company of Scotland for steel plates, the Coventry Chain Company and the Diplock Pedrail Company for the tracks and driving chains, Messrs. Turton Brothers & Matthews for the springs. Messrs. William Foster & Company undertook the whole contract for the six wheeled machines. The construction of all eighteen ships was to be on a cost plus percentage basis.

At this time the supply work of the committee was put upon a business basis, Mr. P. Dale Bussell continuing to be responsible for contracts. It was agreed (24 March) that Colonel Crompton should act as consulting engineer, assisting in the preparation of designs and advising on all technical points. Inspection was to be undertaken by representatives of the Director of the Air Department (Commodore Sueter), who, upon the acceptance of responsibility by the Director of Naval Construction, had agreed to assist the work of the committee as far as possible, particularly through the aid of the Armoured Car Section. He issued a memorandum (30 March) on procedure to be followed in "organising and ordering material for three new squadrons of armoured cars," *i.e.*, the personnel for the proposed 18 landships. Questions of design were to be considered in committee with Director of Naval Construction, Director of Contracts, O.C. Armoured Cars (Lieut.-Col. F. L. M. Boothby), Commander Hetherington and Colonel Crompton. Colonel Crompton remained as before, consulting engineer. Major Hetherington was responsible for supervising construction of the cars, keeping Commodore Sueter informed as to design and proposals to purchase materials. Colonel Boothby undertook the organisation of the three squadrons,

which would be carried out on the same lines as existing armoured car squadrons. An immediate result of these arrangements was the initiation of one squadron, " Number Twenty," which came into being early in June, 1915, and, under the command of Major Hetherington and later of Commander R. W. McGrath, was intimately concerned with the project throughout the war. Close touch with the Landships Committee was maintained in the person of Major Hetherington, who had formerly acted as chief transport officer to the Armoured Car Division and was also a member of the committee. Use was also made by the committee of the Armoured Car Division's experimental ground at the Clement Talbot Works (Barlby Road), Wormwood Scrubbs. Since the cost of design and construction had been assigned to Director of Naval Construction's vote, the Air Department took little active responsibility for these. In one instance, however, and for personal reasons, the Department placed a contract for converting an Allday chassis into a caterpillar tractor.[1]

The problem set before Messrs. William Foster & Company in March, 1915, was to design under Admiralty supervision a tractor armoured against machine gun and rifle fire and with 15 ft. driving wheels. Steerage was to be effected by the flexible attachment of an armoured wagon on two wheels, after the design of a gun and limber. The leading vehicle was to carry the propelling mechanism ; the trailer would take a gun-carriage or attacking force. Engines were to be of the Daimler Standard B type released for this purpose from the Heavy Howitzer Brigade. Armour was to be supplied by the Admiralty from Beardmore's. A wooden model was built at Lincoln and was inspected there by Major Hetherington on 16 May. He reported that, except for modifications in the reverse steering apparatus, the machine was mechanically sound ; but that it had serious military disadvantages. It was 15 feet high, 9 feet wide and 35 feet long. Its size would render it too conspicuous a target. Its bulk and weight would make it a constant menace to traffic in the event of a break-down. There were no means of judging how it would act on varied terrain.

In the meantime, considerable difficulty had been experienced in the design and construction of the caterpillar type of machine. It had been found impracticable to obtain suitable engines, since those available, which were of the Rolls-Royce type, afforded comparatively little power. Thus the advantages of the pedrail track, which needed relatively little tractive effort, were enhanced ; but these tracks had not been so well tested as the existing American caterpillars. Unexpected difficulties were experienced in bringing up the pedrail design from the original one-ton wagon scale to the large scale

[1] This was the order placed with Mr. A. G. Nesfield, Lieut. R. Macfie acting as Admiralty inspector in Mr. Nesfield's workshops. It was subsequently cancelled, but Mr. Nesfield took out provisional protection, 22 June, 1915, for a machine which in some respects foreshadowed the arrangement of " Mother Tank." He exhibited a model at Wormwood Scrubbs (30 June) shortly before the demonstration of the Killen-Strait tractor. It was brought to Mr. d'Eyncourt's notice through General von Donop and Colonel Swinton at a committee meeting in September, 1915.

needed for the landships. Work on the designs, which had been begun by the Diplock Company at its own shops, was transferred to Colonel Crompton's office with a view to overcoming delays (12 April). About the same time, Colonel Crompton began to investigate American types of caterpillar, and received from Mr. W. Strait, manager of the Killen-Strait Manufacturing Company, a proposal for the use of a small armoured Killen-Strait tractor fitted with a wire-cutting apparatus similar to the shearing device commonly attached to ships for ice-breaking. Misfortune was experienced in the choice of the firm to undertake the main construction of the pedrail ships. In April, 1915, a labour dispute at Messrs. Fodens' Sandbach works made it necessary to transfer the contract about 20 April to another firm, the Metropolitan Carriage Wagon and Finance Company. The pattern of armour to be used was subject to constant change, particularly in respect of the introduction of the German reversed bullet, and in consequence calculations of weights and loading fluctuated considerably.

At first the committee was working without adequate knowledge of the military conditions which their weapon would be called upon to meet. An attempt made by Colonel Crompton on 2 March, 1915, to get information from the War Office was only partially successful. Colonel Crompton applied for instructions on the tactical considerations affecting design (9 April). He was sent to France by Mr. Churchill to measure the width of roads, particularly the narrow streets of some of the French towns. The party included Major Hetherington and Lieut. A. Stern, who had joined the Armoured Car Division on 6 December, 1914, and had been acting as deputy to Major Hetherington in connexion with the committee's work since March, 1915. They reached Dunkirk on 21 April, and the next day took measurements of roads and railways as they travelled towards St. Omer, where they were turned back by the military authorities. The Committee therefore fell back on private sources for some part of the information needed.

The immediate result of the visit to France was a radical change in the proposed design of the caterpillar machines. By this date the Committee had departed from the idea of a trench-straddling engine to enfilade the enemy trenches, on the ground that the numerous traverses of a modern trench would seriously limit the range of fire. The project in April was to develop a machine capable of rapid zig-zag movement over the fire-swept zone until it ranged up alongside the enemy's front line, where it would set free its garrison. For increased manœuvring power in action and to enable the landship to negotiate the sharp bends in French roads, Colonel Crompton suggested that the rigid frame should be superseded by an articulated machine with adjustable joints. The proposal was accepted by the Committee, 24 April. Simultaneously negotiations were set on foot with a view to the purchase of American caterpillar tracks upon which the Committee could mount its own platforms.

These changes led to a radical alteration in the nature of the Committee's work, which again became purely experimental. At a meeting held on 7 May, it was decided to limit immediate construction

of the caterpillar type to two experimental landships, the one on pedrail tracks, the other on American "Bullock" or "Creeping Grip" tracks. Contractors' orders were immediately modified. Lieut. Field was sent to the United States to obtain information as to the manufacture of Bullock tracks of which Colonel Crompton, Major Hetherington, Lieut. A. G. Stern, and Lieut. W. G. Wilson had attended a commercial demonstration at Greenhithe on 28 April. Two standard Bullock tracks were ordered about 10 May for experimental purposes. For the construction of the landship itself, it was intended to use extra large Bullock tracks of special manufacture. The order for these was placed in America at the same time.

Thus at the end of May, when Mr. Churchill left the Admiralty, the Department had entered into commitments amounting to about £45,000, without formal sanction and on a matter quite unconnected with the Admiralty. Considerable difficulty had been experienced in evolving a satisfactory type of machine. Both the types first suggested had proved impracticable. The construction of eighteen machines had been abandoned in favour of experiment with entirely new types. The development of a satisfactory design had been hampered by ignorance of the conditions to be met. Military authorities were, however, beginning to show fresh interest in the project. For the entire comprehension of the position, it is necessary here to consider the investigations carried out at the War Office during the first six months of 1915.

IV. Investigations under the War Office, January-June, 1915.

(*a*) FORMATION OF A WAR OFFICE COMMITTEE.

General Scott-Moncrieff took immediate action upon Colonel Swinton's proposal for using armoured caterpillars, laid before him on 4 January, 1915. At his suggestion, and after discussion with General Sir Stanley von Donop (Master-General of Ordnance), General H. Guthrie-Smith (Director of Artillery), and Colonel Holden (Assistant Director of Transport), acting as technical expert, a small informal committee was immediately formed to consider Colonel Swinton's project; but neither Colonel Swinton nor Captain Tulloch was kept in touch with its deliberations. The committee consisted of General Scott-Moncrieff, General Guthrie-Smith and Colonel Holden. Colonel Jackson acted in conjunction with General Scott-Moncrieff and was responsible for the preparation of a trial course at Shoeburyness. The committee's first step was to arrange an inspection at Aldershot on 13 January, 1915, of two Holt caterpillar tractors, which in Colonel Holden's opinion were capable of being armoured and fitted with machine guns.

In the meantime, Mr. Asquith had brought to Lord Kitchener's notice Mr. Churchill's letter of 5 January, 1915, in which were urged not only immediate steps towards developing a particular form of armoured tractor, but also general administrative measures for considering at once the special problems of trench warfare and for guarding against surprise by some entirely novel form of attack. "A committee of engineering officers and other experts ought to be

sitting continually at the War Office to formulate schemes and examine suggestions, and I would repeat that it is not possible in most cases to have lengthy experiments beforehand. If the devices are to be ready by the time they are required it is indispensable that manufacture should proceed simultaneously with experiments. The worst that can happen is that a comparatively small sum of money is wasted."[1] A similar proposal for the formation of a small expert committee including Royal Engineers personally acquainted with conditions at the front had already been made by Colonel Hankey.[2] Mr. Asquith, strongly concurring with Mr. Churchill's recommendations, showed the letter to Lord Kitchener, who agreed to set experiments in train without delay. Shortly afterwards Admiral Bacon's scheme for a bridging device was laid before the Secretary of State, who approved the preparation of one experimental machine fitted with the apparatus and gave instructions for its trial to General von Donop about 12 January. Accordingly the War Office committee negotiated with Admiral Bacon for the preparation of one of the 15 in. howitzer tractors for trial. The fitting of the bridging apparatus was to have been completed at Lincoln by 1 February, 1915, but the preliminary trials there were postponed for a fortnight.

In the meantime, Captain Tulloch had put forward his recommendations through Colonel Jackson (19 January, 1915), raising also the question of the right method of procedure in developing a design and offering the free use of his own services and those of an eminent automobile engineer. He stated his views on the administrative aspect of the question as follows :—" The quickest way to tackle the problem is to enlist the interest of a thoroughly sound professional automobile engineer and designer, who has at his back the facilities for designing offered by a well-equipped drawing office and a factory where the vessels could eventually be built if the design were approved. An artillery and explosives expert in committee with the engineer should not take long in getting out a general design of the whole at a small expense for ultimate approval for the building of a series of vessels if the design is considered likely to be a practical tactical success. . . . The suggestion to form a committee as above described is essential, as experience shows that every design involving several sciences is bound to be a compromise, each aspect having its limitations."[3]

Among the members of General Scott-Moncrieff's committee opinion was divided as to the best means of evolving speedily the necessary design. Colonel Jackson registered his opinion that the only sound plan was to let a committee " build up from the egg," beginning with the requirements and possibilities and going on to the design. He thought that of the machines under consideration it would be impracticable to use the Holt caterpillars, while little was known of the bridging machine. Colonel Holden considered that so much time would be taken in working out an entirely new design that the war would be over before the engine was ready. Hence the only useful action for the moment was to experiment with the engines

[1] Appendix II. [2] Appendix I. [3] Appendix III.

available. He personally supported the caterpillar type owing to its power of negotiating obstacles which no wheeled machine, however large, could overcome. At the same time he agreed that the matter should be left to a small committee as already arranged. General Guthrie-Smith agreed that the caterpillar seemed the first step towards a cross-country vehicle and that progress must be made step by step. General Scott-Moncrieff regarded the investigation as to the two available machines as " concerning the present intention only," suggesting that the arrangement of armour and mountings should be worked out in advance, and that the evolution of the " land-cruiser " should be considered jointly by experts as suggested by Captain Tulloch. General von Donop ruled, on 2 February, 1915, that "it would be advisable to await the trial of the caterpillar and of Admiral Bacon's engine of war before going further with the development."

(b) TRIALS OF A HOLT CATERPILLAR.

The Committee tested the 120-h.p. Holt caterpillar engine and truck from Aldershot over a course which had been prepared at Shoeburyness, on 17 February, 1915. The tractor dragged a truck weighted to 5,000 lb. with sand-bags representing guns and mountings, armour, crew and ammunition. Weather conditions were unfavourable, the ground was saturated and the trenches half full of water. The tractor with the trailer negotiated the first obstacle, *trous-de-loup*, without other difficulty than the breaking of the coupling, which was remedied. In crossing a double line of fire-trenches it cleared away the entanglements effectively, but failed twice to extricate itself and the trailer. No attempt was made to negotiate the other obstacles, a covered shelter trench and a sunk entanglement, which were regarded as obviously beyond the machine's powers. Colonel Holden considered that no modification of the engines used would overcome these last two obstacles. General Guthrie-Smith thought that any use of the caterpillar for the attack of trenches seemed out of the question; but Colonel Jackson pointed out that the machines used in the trial were obviously too small for their purpose. He considered it possible to design such a machine to given conditions of weight, armour and armament, but could give no opinion as to the time it would take.

After further discussion with General Guthrie-Smith, General von Donop decided, on 26 February, 1915, that the investigations were unlikely to lead to success on account of (1) the time required for evolving a design and manufacturing machines in sufficient numbers, (2) the great weights involved, (3) vulnerability to gun-fire, and (4) the difficulty of movement over ground likely to be occupied by the enemy. At the same time, he was ready to reconsider his opinion should a competent person prepare and submit a design. General Scott-Moncrieff and Colonel Holden declared themselves unable to name any person competent to design a land-cruiser, not too heavy, that would cross any country and negotiate the usual fences. The one, however, suggested that advice might be given by the President of the Institute of Civil Engineers, the other named Messrs. Hornsby, of Grantham, as the only British firm with the necessary experience.

(c) Trials of the Bridging Device.

No further steps were taken by the War Office Committee until the question of the bridging device was again raised early in May. Representatives of the Coventry Ordnance Works then applied for permission to examine the trial course. In response to enquiries made by General von Donop, shortly before 19 May, the firm hastened to prepare the special tractor on behalf of the War Office. The machine was tried on 9 June, over the same course as the Holt caterpillar, but under more favourable weather conditions. It was a Foster-Daimler 105-h.p. tractor taken from the 15 in. howitzer equipment, and fitted with an 11 ft. bridging apparatus. It had 8 ft. driving wheels, and its front wheels were tandem. The bridge consisted of girders which were lowered to the ground on reaching an obstacle, the machine then passing over them and pulling them clear of the ditch. Driving backwards over them it picked them up and restored them to position, a manœuvre requiring a clear space of about 25 ft. Obviously, therefore, the machine could not effectively negotiate the trial double line of trenches 12 ft. apart, since they could not be bridged together. In order to test its capabilities, the tractor was put at the trenches without using the bridging girders. It stuck in the first trench after successfully crushing the entanglement. It was hauled out by a 120 h.p. Holt caterpillar, which itself crossed the trenches successfully at top speed. The bridging tractor negotiated with its girders other obstacles, viz., a partly-covered trench 6 ft. wide, and *trous-de-loup* of the same width as the girders, and traversed easily a splinter proof shelter until, in attempting to take it at an angle of 45 degrees, the tractor broke through and stuck at an awkward angle. Colonel Holden considered the inability of the machine to cross a double row of trenches an insuperable obstacle to its use in the field. General Scott-Moncrieff did not think that the invention solved the problem. General von Donop thereupon decided (16 June) to take no further action. The tractor was restored at Lincoln to its original form, as a unit of the 15 in. howitzer equipments. Thus the second device investigated by the War Office Committee proved abortive.

CHAPTER II.

EVOLUTION OF THE FIRST TANK.[1]

I. Inter-Departmental Organisation, May to August, 1915.

(a) Formation of a Joint Naval and Military Committee.

Upon leaving the Admiralty, at the end of May, 1915, Mr. Churchill suggested to his successor, Mr. Balfour, that a joint naval and military committee should be formed to ensure the continuation of the scheme. In view of his personal interest in initiating action, he was himself prepared to act as president. Conferences were held at his house and he kept in close touch with the progress of investigations.

Interest in the matter was renewed at the War Office towards the end of May, 1915, when, at the instance of Colonel Swinton, Captain R. G. C. Glyn undertook to enquire what action had been taken and drew up a paper on "the desiderata of mobile shields." Upon this, steps were taken to obtain information as to the machines under construction for the Admiralty. The paper dealt with a mobile armoured shield self-propelled to cover seventy men and two machine guns. This conception of the scheme was shared by the Third Sea Lord, Admiral Tudor, who, on 30 May, 1915, in answer to enquiries made by General Scott-Moncrieff, communicated to the War Office particulars of the Admiralty orders then existing. General Scott-Moncrieff and Captain Glyn examined the Admiralty models and drawings on behalf of Director of Military Operations on 7 June, entering into direct communication with Admiral Tudor and Mr. d'Eyncourt and subsequently with Mr. Churchill. General Scott-Moncrieff proposed the immediate formation of a joint committee to consider the matter, suggesting that the committee should include a representative of the Chief of Imperial General Staff in view of the tactical considerations involved. Consultation with Mr. d'Eyncourt was essential on account of the analogy between the strains to which the machine was exposed and those on a vessel exposed to the action of waves.

The military members of the proposed joint committee were nominated by 15 June, 1915. They consisted of General Scott-Moncrieff (President), Major Wheeler to represent the Directorate of Artillery, Colonel Bird on behalf of the Chief of Imperial General Staff, and Colonel Holden for the Quarter-Master General. A formal invitation to appoint representatives was addressed to the Admiralty on 21 June, and was accepted on 30 June, the Admiralty stating at the

[1]Based upon the same sources as Chapter I, and also upon minutes, etc., of inter-departmental conferences (D.M.R.S. 341, Hist. Rec./R./1940/14), and upon the relevant Admiralty papers (S.01231/15, 02023/16 and C.P.171253/15), and War Office papers (121/Stores/2834 and 94/Firms/F.63, 282).

same time that the matter pertained rightly to the War Office, though close touch should be maintained with Mr. Churchill, to whose personal interest and initiative the inception of the machines was largely due. The project was accepted as a definite military service at a conference held on 3 July, 1915, to discuss the general delimitation of function between the newly-formed Ministry of Munitions and the War Office. The Army Council communicated this decision to the Admiralty, on 7 July, agreeing that close communication should be maintained with Mr. Churchill during the experimental stage.

It had been decided at a joint conference over which Mr. Churchill presided that the function of the War Office representatives should be to fix the purposes and armament of the landships. Accordingly from the first, action taken by Sir George Scott-Moncrieff and the military nominees of the joint committee was restricted to communicating to the Admiralty Landships Committee the conditions to be fulfilled. In conference, and by a letter dated 16 June, they laid down conditions as to armament and crew, rejecting the existing project of evolving a machine capable of carrying four machine guns and a crew of sixty, and maintaining that the primary armament should be for use against machine guns in concrete emplacements and the secondary armament against *personnel*. The armament should be as powerful, and the crew as few, as possible.

(*b*) Official Specification of Military Requirements.

A formal communication from the army in the field on the practicability of introducing a "landship" was sent to the War Office by Sir John French on 22 June, 1915. He forwarded a paper[1] on "Machine Gun Destroyers," in which Colonel Swinton had submitted to the General Staff, G.H.Q., on 1 June, 1915, an elaboration of his previous proposal to utilise armoured caterpillars. In the intervening months (January to May) the enemy had greatly strengthened the network of trenches and strong points forming his defensive system on the Western front, and by the use of numerous machine guns had succeeded in checking with a minimum number of men the offensive efforts of the British. Colonel Swinton had during this time continued to urge that the project should be taken up, being convinced of its necessity by the conditions attending the British attacks in March, April, May and June, 1915. The Engineer-in-Chief (General G. H. Fowke) was not in sympathy. He considered that the main problem was to prove the practicability of constructing a machine. Sir John French forwarded Colonel Swinton's reply to criticisms made by General Fowke and a rough estimate, dated 15 June, 1915, of the weight and capacity of the proposed machine, based on what was known of existing Holt or Hornsby-Ackroyd caterpillars. The Commander-in-Chief wrote as follows :—"There appears to be considerable tactical value in the proposal which adapts the peculiar qualifications of the caterpillar mode of traction to the transport of

[1] Appendix IV.

a species of armoured turret across cultivated and uneven ground, especially in connection with the trench warfare which is the feature of the present operations, and particularly if the production of these machines be a surprise to the enemy."

He added that the papers showed the governing factor to be (1) whether such machines were available and could be adapted, (2) if not available whether they could be made, and (3) what would be their weight and over-all dimensions. These points could only be decided by reference to manufacturers of such machines. He desired that the proposal should be laid in secret before some competent firm and suggested consultation with the Admiralty. Pending the opinion of a competent manufacturer, only approximate maximum requirements could be stated. These were set out in Colonel Swinton's statement of 15 June. He computed sixteen tons as the maximum weight of the engine when fully manned, equipped, and armed with one 2-pounder Q.F. Maxim and six Madsen rifles, unless the weight could be sub-divided for transport on the principle of the 15-in. and 12-in. howitzers. He estimated the speed at four miles per hour on the flat. He considered that the destroyer should be able to cross a ditch four feet wide without climbing, climb in and out of a broader cavity, scramble over a breastwork and tear a way through any entanglement. The armour should resist the German steel-cored armour-piercing and reversed bullets.

These conditions, with those already formulated by the military representatives on the joint committee, became the working basis for development of a design and formed the first official specification of the requirements to be met. They were discussed (30 June) between General Scott-Moncrieff and Mr. d'Eyncourt, who promised to develop the design on the lines proposed, but feared it might be impossible to fulfil all the conditions then proposed. These were that speed should be between two and four miles an hour; that the machine should travel backwards or forwards, if possible at an equal rate; that gaps up to 5 ft. wide should be bridged directly without dipping into them, and gaps above 5 ft. should be climbed; that petrol and water should be carried for 20 miles; that the landship should climb parapets 5 ft. thick and 5 ft. high, having an exterior slope 1/1 and a vertical interior slope; and that the total weight should not bring a greater strain on bridges than that produced by 14 tons on an axle with a pair of wheels. The crew should consist of ten men with two machine guns and one light Q.F. gun; but General Staff, in view of the articulated design, preferred six 2-pdr. guns, four Maxims and 25 men to each pair of machines. All these conditions were subject to modification.

(c) CONTINUATION OF EXPERIMENTS UNDER THE ADMIRALTY COMMITTEE.

While the project was thus gaining official recognition from military authorities, the Admiralty Committee continued its investigations under sanction obtained verbally by Mr. d'Eyncourt from

the new First Lord, Mr. Balfour, on 1 June, 1915, and formally confirmed on 22 June. In the meantime, the secretary to the committee, Lieutenant Stern, had himself taken offices for its use at No. 83. Pall Mall.

The order for a 15 ft. wheel machine was cancelled on 2 June, and two alternatives were then proposed by W. Foster & Co. The one was for a single machine with 8 ft. driving wheels, in which articulation was abandoned in order to secure independent action and ease of steering and to reduce weight. The floor area would however be restricted and danger would arise from confining an internal combustion engine with nearly red hot pipes close to high explosives and petrol. The second project was to place the tractor behind the trailer in order to diminish the target presented, transmitting the power through an armoured electric cable. This suggestion proved impracticable, and Mr. Tritton was instructed on 9 June to discontinue altogether the work upon the wheeled type of machine. At a committee meeting on the previous day it had been agreed to compensate the firm by placing with them orders in connection with the caterpillar type.

Experimental work was continued with caterpillar machines. The standard Bullock tracks arrived on 16 June at the works of MacEwan, Pratt & Co., Burton, where Lieut. W. G. Wilson carried out experiments to test the stresses in the articulated machine and obtain data as to tractive power and grip. The Admiralty Committee had authorised the purchase of a small Killen-Strait tractor which had already been used for experimental purposes at the R.N.A.S. ground, Wormwood Scrubbs. Successful experiments in wire-cutting were carried out by Major Hetherington with this machine, fitted with a torpedo-cutter attachment, while Lieutenant Symes made arrangements for fitting to it one of the turreted bodies from an R.N.A.S. armoured car. The small pedrail wagons at Wormwood Scrubbs were also fitted with shields as a protection for advancing infantry. On 16 June, 1915, the committee was reorganised. Lieutenant A. G. Stern was formally appointed secretary. Lieutenant W. G. Wilson, an officer of Squadron 20, who had been engaged upon the technical aspects of the problem since the previous April, became a member of the committee.

Immediately after the receipt of definite conditions from the military authorities, Colonel Crompton was instructed to concentrate upon their fulfilment alone. Accordingly the man-carrying machine was abandoned and it was decided, on 6 July, 1915, to proceed immediately with a full-scale matchboard model of a landship to meet the War Office specification. For this purpose Colonel Crompton hired No. 12, Drayton Mews, where work was begun by a Belgian foreman, on 9 July, 1915. The model represented one-half of an articulated machine, articulation being insisted upon by Colonel Crompton as the only means of meeting the military requirements as to weight. Steering was to be effected by hydraulic power, which was also to be utilised for climbing. The guns were to be mounted in one or two turrets. The provision of suitable engines was still one of the chief problems.

The Metropolitan Carriage Wagon and Finance Company, contractors for the main construction, were at this date under very heavy obligations for other military orders, which were about to be increased. At the request of Sir Percy Girouard it was accordingly arranged to release the firm from the landship contract. Mr. Tritton agreed to undertake the building of the frame and erection of the complete machine on 12 July, sending his draughtsman to obtain particulars from Colonel Crompton on 19 July, 1915. It was becoming particularly urgent that the Committee's work should make some definite progress. At a meeting held on 22 July, it was decided, at Mr. d'Eyncourt's suggestion, that Mr. Tritton should carry out a separate order for one single machine in order to test the possibility of working the two halves of the articulated ship independently by adding one or two sets of steering wheels or steering caterpillars. Mr. Tritton had offered to provide a Foster-Daimler engine and worm-gear which would be more efficient for the purpose than the engines otherwise available. A definite order was accordingly placed with W. Foster & Co. on 24 July, 1915, for the construction of one or more landships up to a total not exceeding twelve, and on terms similar to those previously arranged for the big wheel tractors. Finally Mr. d'Eyncourt decided, on 30 July, 1915, that the firm should become responsible under the Admiralty Committee not only for constructional work but also for the development of the design with assistance from Lieutenant Wilson, who acted for the Committee. For this purpose it was arranged that the special Bullock tracks should be sent to Lincoln. The material for the pedrail vehicle had already been transferred to the Trench Warfare Department towards the construction of a flame-projecting device.

(*d*) SCHEME FOR MOUNTING A FLAME-PROJECTOR ON A CATERPILLAR.

Captain T. G. Tulloch had renewed his appeals to Colonel Jackson for accelerated action on 7 June, 1915, deploring "the lack of imagination which invariably left the initiative to the Germans and the destructive criticism which had delayed the introduction of new materials for many years." He maintained that nothing short of some very revolutionary practice would result in any serious advance. Twenty or thirty machines such as the land-cruisers or land-destroyers which had been described by him on 19 January could be readily improvised if the motors were purchased from stock. Improvisation was necessary in order to expedite delivery, since it was "more than dangerous to assume that the war would only last for another year."

Colonel Jackson was himself convinced that a large type of armoured tractor could be designed and constructed in a practicable time. At the same time he had under consideration flame-projecting devices to meet anticipated attacks with an armoured spraying car then said to be in course of manufacture by Krupp. On 24 June, 1915, he received from General Scott-Moncrieff and General von Donop approval in principle of a project for mounting a flame-projector on an armoured caterpillar.

The vehicle, as projected about this time, was to be an egg-shaped armoured car, 40 ft. by 13 ft., and overhanging its wheel-base fore and aft. It was to be driven by two sets of six-cylinder engines with a total power of 180 to 206 h.p., developing a speed of from five to six miles over rough ground. It would be fitted with petrol and compressor tanks. It would also carry three machine guns. Its total weight manned and equipped would be 35 tons. It would be mounted on two caterpillar units of the pedrail type.

Negotiations for the construction of the vehicle were already in hand with the Aster Engineering Company, Wembley, and the Pedrail Transport Company, Putney. Existing engines for a single machine were taken over from the Aster Company, who placed a sub-contract with the Pedrail Company for the tracks. The material ordered by the Admiralty Committee for their pedrail landship was taken over during July, 1915. It included dies and templates and the pedrail chains made by the Coventry Chain Company. Colonel Crompton also provided drawings, specifications, and certain conclusions as to weight and stress for the use of the main constructors of the flame-projector vehicle, Messrs. Stothert & Pitt, of Bath.

(*e*) Acceptance of ultimate Authority by the Ministry of Munitions.

Upon 23 June, 1915, General Jackson's section of the Department of Fortification and Works was transferred to the Ministry of Munitions and became the Trench Warfare Department. Dr. Addison, for the Minister, concurred in an application made by General Jackson to the Under-Secretary of State, on 8 July, for authority to purchase materials for the flame-projector caterpillar. The Minister of Munitions thus became responsible for this type of machine.

Mr. Lloyd George's interest in the development of a landship had already been aroused by an exhibition given before him and Mr. Churchill by R.N.A.S. officers at the Wormwood Scrubbs experimental ground on 30 June. Major Hetherington then demonstrated the capacity of the Killen-Strait tractor for forcing barbed wire and traversing rough and broken ground. The armoured shields on pedrail units and turreted armoured car on the Killen-Strait tractor were inspected at the same time as well as other experimental work carried out at the Wormwood Scrubbs ground. As a result of this demonstration, Mr. Lloyd George was persuaded by Mr. Churchill to take over from the Admiralty responsibility for these as well as other projects for purely military purposes. A verbal arrangement with Mr. Balfour to this effect was officially confirmed on 17 July, the original intention being that the execution of these schemes should lie with the Inventions Department of the Ministry of Munitions. Dr. Addison at first delayed sanctioning further action in the construction of landships until he "should have assurance from responsible authorities that they are wanted and likely to be useful and used if made." On 9 August, 1915, he received assurances from the Committee that a machine would be ready for trial in two or three

weeks. It was then agreed that the Admiralty Committee should continue its work upon design and construction until a satisfactory experimental machine should be produced, after which responsibility for supply in bulk should rest with the Inventions Department of the Ministry. It was simultaneously arranged that the R.N.A.S. Squadron 20 should be transferred from Wormwood Scrubbs to the Trench Warfare Department's experimental ground at Wembley, where it would serve both the Admiralty Committee and General Jackson. On 2 August, 1915, Dr. Addison confirmed the sanction for transfer of the main contract to W. Foster & Co., provisional concurrence having in the meantime been given by the Director of Munitions Contracts. Arrangements had already been made for housing the office of the Committee within the buildings of the Ministry.

While the agreement thus reached between the Admiralty and the Ministry of Munitions prevented any check in the development of a landship, at the same time it rendered anomalous the position of the joint naval and military committee under Sir George Scott-Moncrieff. In August, 1915, the arrival from G.H.Q., France, of data touching German trenches, collected at Colonel Swinton's instigation, again raised the question of military responsibility. Colonel Swinton had returned to England in the meantime as assistant secretary to the War Committee. On 26 August he approached the Prime Minister, who agreed to the appointment of a small inter-departmental conference to co-ordinate action. The conference met on 28 August.[1] It was then agreed that the Admiralty Landships Committee should continue experimental work in designing and constructing a suitable type of landship, keeping the Munitions Inventions Department informed of its action and taking instructions direct from the War Office as to the type of machine, its protection and armament. The Admiralty Committee was to continue to use the personnel, transport and supplies of the R.N.A.S. Squadron No. 20. When the design and experimental work had been carried as far as was desirable, the Admiralty Committee was to transfer the work to Munitions Invention Department. The function of the War Office would be to convey its requirements directly through its representatives (Colonel Bird and Major Wheeler) to the Admiralty Committee. The Trench Warfare Department of the Ministry was to continue investigating the special type of "land-cruiser" for carrying flame-projectors, communicating directly with the Admiralty Committee on points of design and construction.

Accordingly, the work being done was set on a clearly defined basis. The Admiralty Landships Committee carried on experimental work for the next five months, obtaining information as to general

[1] Present:—Sir G. Scott-Moncrieff (chairman), Colonel W. D. Bird (General Staff, War Office), Lieut. A. G. Stern (Secretary, Admiralty Committee, representing Mr. d'Eyncourt); Mr. E. W. Moir (Comptroller, Munitions Inventions Department), Captain T. G. Tulloch (Ministry of Munitions), Brigadier-General Jackson and Captain Vincent (Trench Warfare Department), Lieut.-Colonel Swinton and Lieut.-Colonel W. Dally Jones (Assistant Secretaries, Committee of Imperial Defence).

requirements from Colonel Swinton, Colonel Evans and Major Wheeler, who acted as military members of the Committee, in order to expedite decisions. The question of departmental responsibility was once again raised within the Admiralty; but at Mr. d'Eyncourt's urgent request, permission was given on 26 October, 1915, for the continuation of the Committee's work on design up to the point at which production in bulk could begin.

II. Evolution of the first Tank, August, 1915—January, 1916.

(a) Development of "Little Willie" and the "Centipede."

The decision of 22 July, 1915, to order a single machine from W. Foster & Co. was the first step towards the abandonment of the articulate design. Until the termination of his appointment at the end of August, Colonel Crompton continued to work on the design of a landship, discarding the articulated form about the middle of that month, although he doubted the practicability of building a single ship to meet all the War Office conditions. Lieutenant Wilson's experiments at Burton had proved that when two vehicles were coupled together they might help each other over a gap in smooth ground, but on rough ground the coupling would not stand the strain, and on certain ground one machine could not help the other at all. Mr. d'Eyncourt gave verbal authority to Mr. Tritton to proceed with the design of a single vehicle on 30 July, and written instructions to this effect followed on the next day.

It was agreed on 4 August, 1915, that the special 9-ft. Bullock tracks on order from America should be sent to Lincoln, and that Mr. Tritton's machine should be fitted to them. Good progress with the design was reported on 9 August at a conference between Mr. d'Eyncourt, Mr. Moir (for Ministry of Munitions), Lieutenant Wilson and Mr. Tritton. The construction of a machine to Mr. Tritton's design began in the Lincoln workshops on 11 August. This vehicle was variously known as "Little Willie," the "Tritton" or the "Juggernaut." It was built to carry one gun in a central turret. It weighed 16½ tons. It could climb a slope of ½ and cross a gap 4 ft. 6 in. wide; but it failed to meet the War Office condition of climbing a vertical parapet 5 ft. high. Its main defect was instability, due largely to the mounting of the gun in a turret and the consequent height of the centre of gravity. On 17 August, Mr. Tritton devised a machine to have a hinged tail with automatic balance. During this month Lieutenant W. G. Wilson divided his time between the experimental ground at Burton and the Lincoln workshops, having been appointed inspection officer with instructions to work in conjunction with Mr. Tritton. This co-operation of an expert engineer working in his own shops with a technical adviser appointed by the Committee met with speedy success. In discussing with Mr. Tritton the design of 17 August, Lieutenant Wilson suggested the use of all-round tracks. Pooling their ideas, Mr. Tritton and Lieutenant Wilson then worked out the main features of the final design, calling it the "Wilson" or "Centipede," and including in the pattern the hinged

tail as a supplementary means of steering. The main difficulty foreseen was the construction of tracks of the requisite length. While this formidable problem was still under discussion between Lieutenant Wilson and Mr. Tritton, the latter reported progress on " Little Willie " to Mr. d'Eyncourt on 23 August, and was challenged as to its capacity for meeting the military requirements in mounting parapets. Admitting its inability, he put forward the scheme for the " Centipede," making a pencil sketch and receiving verbal orders to proceed with one machine of this type.[1] Mr. d'Eyncourt made a note of this meeting as follows :—

" (1) Going on well."

" (2) Proposal for next with equivalent of 50 foot wheel. All parts can be made in England. I think well of this. Wilson's idea."

Thus by 23 August, 1915, the conception of the original tank had reached its final form, and a wooden model was immediately put in hand. Owing to its rhomboidal shape it could mount a 4 ft. 6 in. parapet. The all-round tracks enabled the guns to be placed within their circuit, increasing stability by lowering the centre of gravity. An increased field of range was secured by mounting the guns in sponsons.

The problem of devising a suitable track remained to be surmounted. Tested on " Little Willie " the special Bullock tracks failed. This machine first moved on 8 September, 1915, running in the Lincoln yard the following day. It was then sent to Cross O'Cliff Hill, Lincoln, where trials with a modified type of Bullock track on Sunday, 19 September, showed the need for a longer track confined to prevent slipping. These trials were attended by Mr. d'Eyncourt and Colonel Swinton, who also inspected a "mock-up" of the "Centipede." Instructions were immediately given for the development of the "Centipede" without dismantling " Little Willie " and the construction of the two machines proceeded simultaneously in the Lincoln workshops. The Balata belting then suggested for use for the tracks was rejected as unsuitable and work on designing a suitable track was recommenced, the final form of 12 ft. track being devised by Mr. Tritton on 21 September.

At the conference of 28 August, 1915, it had been decided that secret trials of the types then being constructed under the Admiralty Committee should take place as soon as possible at the trench warfare experimental ground at Wembley Park over a course of obstacles to be prepared by the R.N.A.S. Squadron No. 20, in accordance with the information supplied by G.H.Q.

The wooden model of the " Centipede " was ready for inspection by 29 September, when an inter-departmental conference, organised by Colonel Swinton, took place in Mr. d'Eyncourt's room at the Admiralty. The main object of the meeting was to settle certain points which would govern the future development of the design.

[1] Entry in D.N.C.'s diary 23 August. Sir W. Tritton puts the date at 24 August.

There were present three members, including the Secretary, of the Experiments Committee, G.H.Q., France, in addition to representatives of the War Office, Ordnance Board and Ministry of Munitions.[1]

Particulars of "Little Willie" were given and photographs and drawings were examined. The meeting then adjourned to Wembley Park, where the wooden model of the "Centipede" was demonstrated. It was admitted that while this machine fulfilled the military conditions in that it would cross a trench 8 ft. wide and climb a parapet 4 ft. high, it was in fact a compromise, particularly with regard to dimensions and weight. It could, however, be transported on the French railways. Its total weight (with petrol, water and two men, but without guns or ammunition) was calculated as 22 tons. It had a speed of two miles per hour. It was 7 ft. 6 in. high and 26 ft. long, dimensions fixed as the result of detailed experiments determining definite ratios between the length and height of the machine, the width and height of the gap to be crossed and the parapet to be climbed.

The conference made certain decisions, afterwards referred to the Experiments Committee for confirmation. It was agreed that the general development should take place along the lines of the "Centipede," but that efforts should be made to increase the speed to four miles per hour. The nature of the armament was laid down. It was decided that the armour should be of bullet-proof steel, the front being 10 mm. thick in order to stop the German reversed bullet at 10 yd., the sides 8 mm. thick and the roof 6 mm. The crew should consist of eight men trained both to drive the machine and to man the guns.

Construction of the "Centipede" was pressed forward in the Lincoln shops. At the same time, work was continued on "Little Willie." The gun turret was removed to lower the centre of gravity, and the machine thus modified and weighted with pig-iron slabs was tested at Burton Park, Lincoln. The new form of special 12 ft. track was tried on this machine pending the completion of the "Centipede." This design solved the problem of providing a track of the great length required and capable of carrying the whole weight of the vehicle. It was finally adopted for the "Centipede."

(b) ARMAMENT AND ARMOUR.

While these developments were in progress active steps were being taken to evolve suitable armament and armour. The arrangement and mounting of the guns and the details as to gun-ports, sponsons and sighting were considered personally by Mr. d'Eyncourt, aided by Mr. F. Skeens, a temporary Assistant Constructor at the Admiralty. During the first half of 1915 the projectors of the scheme had conceived

[1] Present:—Mr. d'Eyncourt (Chairman), Major T. G. Hetherington, Lieut. W. G. Wilson, Lieut. Stern, Lieut. Symes (Admiralty Committee), Major W. H. E. Segrave, Colonel Carte, Colonel Holden (War Office), Lieut.-Colonel R. N. Harvey, Major J. T. Dreyer, Major the Hon. C. H. C. Guest (Experiments Committee, G.H.Q., B.E.F.), Captain R. A. Hopwood (R.N.) and Colonel Goold Adams (Ordnance Board), Brig.-General Jackson, Mr. Moir, Captain T. G. Tulloch (Ministry of Munitions), Capt. F. E. D. Acland, Mr. Tritton, and Colonel Swinton.

of machine guns as the primary armament for the landship. But a heavier type was called for by the military conditions defined in June, 1915, when Colonel Swinton suggested one 2-pdr. Maxim and six Madsen guns. Captain Tulloch had already proposed the use of four 2-pdrs. for the heavy land cruiser. " Little Willie " was designed to meet military requirements by carrying one 2-pdr. in its turret. The first wooden model of the " Centipede " was arranged to take one 2-pdr. and one 2·95 in. Q.F. mountain gun for comparison. The 2-pdr. was rejected as too light by the conference of 29 September, 1915, but only four of the mountain guns were available. Eventually an armament of two 6-pdr. Q.F. guns and two machine guns was adopted for the " Centipede," the Admiralty undertaking (24 December, 1915) to provide guns and mountings up to a total of 100 by the following June. The adoption, as main armament, of the 6-pdr., firing a fairly heavy projectile, but not too heavy to enable 100 rounds to be carried, was strongly urged by Mr. d'Eyncourt, who knew the capabilities of the naval 6-pdr. gun.

In the meantime, exhaustive experiments against bullet-proof plate were carried out at Messrs. Beardmore's works under the supervision of Major Hetherington and Lieutenant Symes, and with a German machine gun and ammunition borrowed by Colonel Swinton from the War Office.

(c) Adoption of the " Centipede " as Prototype or " Mother Tank."

In the first week of December, 1915, " Little Willie " and the " Centipede " were inspected at Lincoln by Mr. d'Eyncourt, Major Wheeler, Major Tulloch, Lieutenant Stern and others. The efficiency of the " Centipede " was then considered so much the greater that all further efforts were thenceforward concentrated upon its completion. The machine first ran in the yard at Lincoln on 12 January, 1916, and first went out of the works the day following. Its trials at Lincoln were entirely successful, and orders were thereupon given to Messrs. Foster to forward it to Hatfield Park for inspection on behalf of the Army Council.

Meanwhile, military interest in the scheme had been quickened by representations made to the Commander-in-Chief by Mr. Churchill, then in France. At the request of Sir John French he drew up a paper on " Variants of the Offensive " (3 December, 1915), emphasising particularly the advantages of attack by armoured vehicles with caterpillar tracks, which were described as being " movable machine-gun cupolas as well as wire-smashers," capable of traversing any ordinary obstacle, and vulnerable only to a direct hit from a field gun. The paper was read by Sir Douglas Haig on Christmas Day, 1915, and Major H. J. Elles of the G.H.Q. Operations Division was thereupon instructed to obtain from Mr. Churchill information touching the action already taken in manufacturing armoured caterpillars. As a result of further inquiries at home, Major Elles reported on 8 January on the position of the Trench Warfare Caterpillar, " Little Willie,"

and the "Centipede." After a preliminary trial Mr. d'Eyncourt notified Lord Kitchener that the machine was ready for him to see and that it fulfilled all the requirements laid down by the War Office, "which had never previously been met by any machine."

Instructions were given by Lord Kitchener on 29 December, 1915, for a trial of the sample machine, stating that "the first thing . . . would be to test its practical utility under field conditions; without such a test we may be wasting material and men uselessly." Hatfield Park had been lent by Lord Salisbury for the purpose by arrangement made with Mr. d'Eyncourt in the previous October, and a working party began to construct trenches and obstacles shortly after 6 January, 1916. A private and satisfactory inspection of the machine took place on this course on 29 January. The following day Mr. d'Eyncourt informed Lord Kitchener that the "Centipede" could be demonstrated on Wednesday, 2 February, when the official trial took place in the presence of Lord Kitchener and officers of the General Staff, War Office, officers of the Staff of the Commander-in-Chief, the First Lord and other members of the Admiralty and the Minister of Munitions. The machine was afterwards demonstrated before the King on 8 February, 1916. The official tests, viz., the climbing of a parapet of 4 ft. 6 in. and the crossing of a gap 5 ft. wide "proved nothing to it . . . It could easily cross a 9 ft. gap after climbing a 4 ft. 6 in. perpendicular parapet." The programme further included a test approximating to conditions of active service over a course where, leaving a specially prepared dug-out, the machine climbed over the "British" defences reduced for its passage, broke through the wire-entanglements in front, crossed two shell-craters, traversed water-logged ground, climbing a slope and then the "German" defences, and finally turned round on the flat, passing down the marshy bed of a stream and climbing a double parapet.

In a letter of congratulation to Mr. Churchill (14 February, 1916) on the success of his "original project," Mr. d'Eyncourt described the achievements of the "first landship ('tanks' we call them)" as follows:—"Wire entanglements it goes through like a rhinoceros through a field of corn. It carries two 6-pdr. guns in sponsons (a naval touch) which can fire right ahead and enfilade the trenches on the broadside. . . . It is proof against machine-gun fire. It can be conveyed by rail (the sponsons and guns take off, making it lighter), and can be put together ready for action and proceed independently at short notice. . . . The wheels behind form a rudder for steering a course and also absorb the shock over banks, but are not absolutely necessary." Thus the "Centipede" was accepted, becoming a prototype of all tanks and being colloquially called "mother" although she was technically a "male" machine.

(*d*) Completion of the Caterpillar Flame-Projector.

Suggestions somewhat similar to the project for the flame-projector caterpillar under construction by the Trench Warfare Department were received from Major A. R. Glasford in a paper on the neutralisation of the trench as an obstacle, forwarded through G.H.Q., France, on

3 September, 1915. He proposed to carry the attack with lethal gases right into the enemy lines by means of a pedrail caterpillar, of which the main armament would be a liquid, such as hydrocyanic acid, deadly in effect but not so persistent as to hamper the attacking infantry.

The design and manufacture of the pedrail machine carrying a flame-projector was then already in progress in accordance with the arrangements made at the conference of 28 August, 1915. Actual construction of the parts of this machine was practically complete by 17 February, 1916, but the department had not devised armour sufficiently thick to be invulnerable to machine-gun fire and yet light enough for its purpose. Messrs. Stothert & Pitt constructed the main frame and assembled the parts at Bath. The machine was commonly called the "Trench Warfare" caterpillar or tank. It was ready to leave the works on 22 July, 1916. As completed it ran on two pedrail units arranged tandem and driven by Aster engines. The frame was 33 ft. 4½ in. long by 9 ft. 4 in. wide. The machine was sent to Porton for trial about 2 August, 1916, in connection with a proposal made by General Jackson to Sir George Scott-Moncrieff, on 22 May, to use it for traction purposes. On the road it developed certain weaknesses in the roller-beds and tests were postponed while these were remedied. The impracticability of using on *pavé* roads the particular type of pedrail feet fitted for crossing ploughed fields ultimately prevented the use of this machine as a lorry, but a new design of pedrail lorry evolved May, 1917, was based on the experience and drawings of the Trench Warfare Department.

III. Preparations for Manufacture in Bulk.

Before responsibility for manufacture could be definitely taken by the Inventions Department of the Ministry of Munitions as agreed on 28 August, 1915, certain circumstances led to a modification of this decision. In a letter of reservation to the conference's recommendations, Captain Tulloch pointed out, on 25 September, that the membership and functions of the Inventions Department and Trench Warfare Department rendered them unsuitable to deal with the matter. He urged that supply should be left with a small expert committee working under the War Office upon the lines of the Flying Corps, and responsible not only for the construction of the landships but also for the training of their crew. Moreover, General von Donop disapproved generally of the procedure adopted at the inter-departmental conference of 29 September. He stated his opinion (19 October), as follows :—" I view with dismay the manner in which this subject is being dealt with. A War Office Committee was appointed for it, the C.I.D. is also dealing with it, a conference decides on what should be done, they are called Admiralty Landships, the personnel is to come from a naval organisation and I am asked about the provision of guns and ammunition [on] the patterns of which I have not been consulted."

It was thereupon agreed to postpone final decision as to the ultimate responsibility for construction in bulk and for the command of any separate unit until the Admiralty had completed the experimental machine.

During November and December, 1915, increasing defensive preparations by the Germans, and especially the elaboration of their machine-gun emplacements, impressed with a need for expedition the believers in the ultimate success of the project, particularly Mr. Churchill and Colonel Swinton. Colonel Swinton emphasised the importance of a speedy decision as to procedure in a memorandum forwarded to General Scott-Moncrieff on 18 December. He represented that the Admiralty Committee would shortly have completed the experimental machine, and that immediate action was necessary both to initiate manufacture in bulk by a duly authorised supply department and to ensure the retention of R.N.A.S. Squadron No. 20, whose members were peculiarly fitted to supply the personnel of the new service. He suggested that a second inter-departmental conference should be called to discuss future procedure.

This conference was held on Christmas Eve, 1915,[1] and recommended that supply in bulk should be carried out by a small committee to be called the "Tank Supply Committee." Executive and financial responsibility for the actions of the Committee was the subject of lengthy discussion. Officers of the Ministry of Munitions had notified unwillingness to become responsible for a machine of complex nature and resembling chiefly mechanical transport, then not within the province of the Ministry. The Admiralty representatives expressed anxiety to be rid of all "side shows," including the tank, when once experimental work was complete. The establishment of a small supply committee had been approved generally on behalf of the Secretary of State for War; but there was a strong body of opinion against placing final responsibility with the Master General of Ordnance. It was therefore recommended that the new committee should work under direct instructions from the General Staff, War Office, both as to supply and design, deriving financial authority from the accounting officer, under the precedent already established in the case of the Aviation Department. In order to enable the work to be carried out with the maximum of despatch and the minimum of reference, the committee should be free to place orders, correspond direct with any Government Department, and incur any necessary expenditure. A preliminary sum equivalent to the cost of 50 machines should be placed at its disposal. The committee should be responsible for supply of the entire machine together with both primary and secondary armament. As the machines were finished, they should

[1] Present:—Sir George Scott-Moncrieff (Chairman), Rear-Admiral Morgan Singer (Director of Naval Ordnance), Mr. d'Eyncourt, Lieut. Stern (Admiralty Committee), Lieut.-Colonel W. H. Moore, Lieut.-Colonel C Evans, Major E. L. Wheeler (War Office), Brig.-General L. Jackson (Trench Warfare Department), Lieut.-Colonel W. C. Symon, Captain T. G. Tulloch (Supply Department, Ministry of Munitions), Major E. Seagrave (Inventions Department), Major the Hon. C. H. C. Guest (Design Department), Lieut.-Colonel Swinton (Committee of Imperial Defence).

be handed over to the War Office for training purposes. The committee should come into being when the experimental machine had received military approval, and should be under the presidency of Lieut. A. G. Stern, then secretary to the Admiralty Committee. Other members of this Committee and representatives of the Directorates of Staff Duties and of Artillery should also be members. Mr. d'Eyncourt and Captain Tulloch should act as consultants.[1]

Immediately after the successful trials at Hatfield both the Admiralty and the Ministry of Munitions expressed their willingness to become responsible for the work of the Tank Supply Committee. Mr. Lloyd George, with Mr. Balfour's concurrence and with the knowledge that the War Office was about to ask for the supply of 100 machines, signed a charter for the constitution of the Tank Supply Committee on Saturday, on 12 February, 1916. The Army Council made its formal demand for the first hundred tanks the same day.

Financially and executively the new committee was to act under the authority of the Minister of Munitions. It was authorised to arrange for manufacture of tanks generally, with independent powers of purchase, correspondence and finance identical with those recommended at the recent conference. The cost of " Mother Tank " and of the work of developing the original design was borne by the Admiralty vote. The retention of a considerable number of the original members of the Admiralty Committee ensured continuity between the original work of design and the further organisation of supply and development of pattern. The president of the Tank Supply Committee (Lieut. A. G. Stern) had acted as secretary to the Admiralty Committee since the preceding March; Mr. d'Eyncourt consented to advise upon technical and experimental questions; three other members of Mr. d'Eyncourt's committee[2] also became members of the Tank Supply Committee. The remaining three members were Colonel Swinton, Major Wheeler and Captain Tulloch (consultant). The Tank Supply Committee took up its work at the headquarters of the Ministry on 15 February, and held its first meeting to discuss the production of the first hundred machines on 16 February. Its membership was immediately extended to include a representative of the Design Department of the Ministry (Lieut.-Col. Byrne). Its immediate work was the speedy production of the hundred tanks for which the formal War Office demand had been received. The constitution of the committee subsequently underwent certain changes which will be described in the chapters which follow.

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[1] The Conference recommended that the following should be members of the Tank Supply Committee:—Lieut. A. G. Stern (President), Lieut.-Colonel Swinton (C.I.D.), Lieut.-Colonel C. Evans (Directorate of Staff Duties, War Office), Major E. L. Wheeler (Directorate of Artillery, War Office), Major T. G. Hetherington, Lieut. W. G. Wilson, Lieut. K. P. Symes (Director of Naval Construction Committee), Mr. Dale Bussell (Contracts Branch, Admiralty), members; Mr. E. H. T. d'Eyncourt (Director of Naval Construction) and Captain T. G. Tulloch (Ministry of Munitions), consultant members.

[2] Viz., Lieut. W. G. Wilson, Lieut. K. P. Symes, Mr. P. Dale Bussell.

CHAPTER III.

THE BEGINNINGS OF BULK SUPPLY, 1916.[1]

I. Arrangements for the First Production in Bulk.

(a) Early Organisation for Supply.

The Tank Supply Committee took up its work at the headquarters of the Ministry of Munitions on 15 February, 1916. Its first efforts were concentrated upon providing, as early as possible, the 100 machines for which a request had been received from the Army Council three days before. For this purpose, it used to the full that independence of action which had been recommended by the inter-departmental conference of Christmas Eve, 1915, and had been bestowed by Mr. Lloyd George's initiatory charter. The president, Lieut. A. G. Stern, served in a dual capacity as chairman of the committee and as head of the department which fulfilled the executive functions assigned by the charter. The dividing line between the committee and the department was at first ill-defined. The concentration of responsibility in a single business man, who should be of proved capacity and acquainted with previous investigations, had been recommended by Colonel Swinton in December, 1915. Throughout the term of his office, Lieut. Stern contended for methods of production which should follow independent business lines, rather than the normal procedure of a Government Department. As tanks became more and more definitely recognised as a service equipment of the army, efforts to approximate the system of production to procedure in relation to other stores increased. Ultimately, the call for business methods became less urgent than the need for a more formal procedure which should secure, on the one hand, the efficiency of the new arm within the service and, on the other, co-ordination between the production of tanks and of other munitions dependent upon the same classes of manufacturing capacity and raw materials. The development of the administrative organisation for supply was thus very closely interwoven with the actual progress of output and use. These two aspects of production will accordingly be considered side by side in the chapters which follow.

The Committee held its first meeting on 16 February, 1916. Arrangements were made with Messrs. Foster & Company, Ltd., of Lincoln, and with the Metropolitan Carriage Wagon and Finance Company, Ltd., for the production of 25 and 75 machines respectively. The Daimler Company, Coventry, undertook the supply of the necessary

[1] Based mainly upon Memoranda of the Tank Supply Committee for 1916 *penes* Sir Albert Stern, registered papers relating to Tank Programmes (D.M.R.S.341, 341A), Colonel Swinton's papers relating to the Motor Machine Gun Corps (Hist. Rec./R/1940/14) and a departmental history of Squadron No. 20 (Hist. Rec./H/1940/5).

engines. Orders for armour plates were placed with Messrs. Beardmore, Glasgow, Messrs. Cammell Laird and Messrs. Vickers, Ltd., Sheffield, and suitable periscopes and telescopes were soon under construction for early delivery. A suggestion which had been made to spread the orders for the various parts required over a large number of firms could not be put into effect while the number of tanks on order remained limited, since the manufacturers required to spread their output under any order over twenty weeks. Difficulties soon began to be experienced, particularly in the supply of armament for the tanks; and it was in this direction, accordingly, that the work of supply first became differentiated within the department. An individual officer (Mr. Skeens) was made responsible for the armament arrangements of all tanks. The Admiralty were requested to allow their inspector, who was already at the Daimler Works, to inspect and pass the engines on behalf of the Committee. Another officer (Lieut. Symes) was made responsible for the inspection of all armour plate. Beyond this, however, there was no clear cut division of duties nor allocation of responsibilities within the department. The removal of any difficulties experienced was the joint responsibility of all members of the department. This elastic system served its purpose well while production was proceeding on a small scale with comparatively few firms involved. It enabled a comparatively large number of officers to be employed on the rapid removal of any difficulty experienced.

The Tank Supply Committee, in addition to proceeding with the construction of the 100 machines which were ordered, made provision for carrying on experimental work independently of production. In particular, experiments were being carried out (5 April, 1916) for enabling tanks to carry their own means of communication. A type of gun-carrying tank was evolved. Provision of 50 of these was sanctioned by Mr. Lloyd George in June, 1916, in anticipation of a formal War Office demand. They did not, however, come into actual supply until the second quarter of 1917. The task of raising and training the personnel for manning the tanks was entrusted to Colonel Swinton, who also acted as a member of the Committee. A camp was arranged at Thetford to serve as a training ground. As the machines were turned out and equipped by the Tank Supply Committee, they were to be handed over for the purpose of training the personnel to man them. Officer cadets with engineering experience were asked to volunteer for "an experimental armoured car unit." On 16 March, arrangements were made for instruction, with specially selected officers and men of the Motor Machine Gun Corps as a nucleus of two companies. They were formed into a battalion when further reinforcements arrived, and trained on the basis of Colonel Swinton's "Notes on the Employment of Tanks."

(*b*) UNFORESEEN DELAYS.

The Tank Supply Department confidently expected an early output of the 100 tanks which had been ordered. This number was based on the War Office requirement of February, 1916. Although it was double the number recommended by the inter-departmental

committee on the previous Christmas Eve, it was not considered sufficient to maintain the nucleus of organisation for supply. The Army Council accordingly came to the aid of the supply department on 21 April with a formal requisition for 50 more machines, making a total of 150. It was then decided that half were to be " male " tanks, armed with six-pounder guns and machine guns, and half were to be " female " tanks armed only with machine guns. Major Stern undertook that the 150 craft would be ready for transportation to France by the end of July.

Tank supply ranked at this time as one of the three most urgent requirements of the Ministry of Munitions, and the demands of the department were given corresponding priority; but unforeseen difficulties arose, particularly in regard to personnel and provision of spare parts and equipment.

The problem of supplying the necessary spare parts was intensified by a difference of view between the supply department and military authorities as to the " life " of a tank and the need for arrangements to replace parts. Colonel Swinton, as O.C. Heavy Brigade Machine Gun Corps, maintained a certain liaison between the Tank Supply Department and the Director of Staff Duties; but this proved insufficient to create within the department a correct knowledge of army requirements in matters of detail. Major Stern conceived the tank as a " projectile " which was to be regarded as used up when once it had been employed in action. He contended that " training tanks would require spare parts but fighting machines would require spare fighting machines," and that the tank was originally intended for a 50 mile life, while the army regarded its life as indefinite. The need for a repair unit, which then began to assert itself, came as an additional strain to the capacities of the department, and with the call for spare parts, caused considerable delays. These were to some extent aggravated by the slowness with which Hotchkiss guns became available as they were withdrawn from anti-aircraft service.

It became evident that if tanks were to be in action that year, there must be a speeding up of production. The department was short of staff and a limited number of officers, non-commissioned officers and men were despatched from the training camp to the manufacturing centres, whither also detachments of Squadron 20 were detailed. The squadron, which had been lent to the Ministry for experimental work at Wembley, had since been engaged under Commander McGrath in testing and transporting tanks. On 19 May, the Admiralty proposed to withdraw Squadron 20 during the following two months, since the Armoured Car Division of the R.N.A.S. was about to be disbanded. This threatened to hamper the work both of the supply and the training departments of the new enterprise, as the training camp looked to the transfer of promising personnel from the squadron to form a nucleus of the fighting corps. Accordingly, the withdrawal of the squadron was abandoned at the earnest solicitation of Mr. Lloyd George.

A limited number of training machines, similar to Mother Tank, but with boiler plate instead of hardened steel armour, arrived at Thetford early in June, 1916, and it was anticipated that crews for 75 tanks would be fully trained by the end of July in any case. By the middle of July it was realised that the 150 tanks promised for transportation by the end of that month would not be available until the end of September. Nevertheless the Army Council again gave a continuation order for 50 more tanks (25 July, 1916), although it was still uncertain whether more tanks should be ordered or the type changed. The French were about to hold experiments with their tanks, and it was thought desirable to benefit also from their experience. The object of the further order which had been given was to keep contractors at work on tanks and maintain the organisation for supply which was being built up. Mr. Montagu, who had become Minister of Munitions, represented that the order was insufficient for this purpose. The Army Council readily increased its order by another 50, making a total of 250 tanks on order, before experience had shown to what extent the tank, as then designed, could be of use in the field.

Meantime the organisation of the Heavy Brigade (Tanks) Machine Gun Corps, was proceeding. It was to consist of six companies, each of four sections, comprising six tanks and one spare tank and crew per section, with workshops and transport, and usually subdivided into three subsections, each of one male and one female tank.

It was understood that one section of six tanks would be on the seas by the first week in August. If possible a double company workshop was to accompany them. The remainder were to follow in lots of two sections, twelve at a time, at weekly intervals and, except for the first outfit, were to draw ammunition from the ordinary channels.

(c) Dissensions as to Early use in the Field.

The prospect of an early employment of tanks in active operations did not meet with the approval of the supply authorities. The headquarters organisation for design and production had been re-arranged early in August, 1916, in order to obviate some confusion resulting from the lack of definition between the Tank Supply Committee and the Tank Supply Department. It was pointed out by Major Stern that he and his staff could alone be held responsible on questions of supply; that the different members of the Committee had been appointed for their very special knowledge on particular subjects, and that it was the name only of Supply Committee which had caused any misunderstanding as to the duties of its members. The Committee was thenceforward styled the "Advisory Committee of the Tank Supply Department"; and a sub-committee, consisting of Mr. d'Eyncourt, Mr. Bussel and Major Stern, was appointed to decide on questions of design and policy.

It was this sub-committee which urged that the first employment of tanks should be in large numbers, pointing out that whereas 150 tanks would be available during September, 350 more could be ready in January if orders were placed immediately; and that, therefore, the tanks should

not be employed till January, in order to ensure greater final success and in order to enable crews to have longer training. At the same time, it was admitted that the tanks under production were not supplied with the necessary spares. "My department," contended Major Stern, "was originally given an order to produce 150 tanks with necessary spares, and I was under the impression that these would not be used until completed. Therefore the spares would not in the ordinary way be available until the 150 machines were completed." These and similar attempts of supply authorities to intervene in the regulation of active operations were of frequent occurrence and were invariably resented. Any intimate knowledge of the views and requirements of the army was hampered by the lack of an authoritative military representative upon the Committee, while the Supply Department, with its attention concentrated on output, was developing its manufacturing organisation rather than its procedure for ascertaining military requirements. Divergencies of opinion, intensified by the lack of a means for detailed discussion, tended to increase the difficulties of co-operation between the producers and users of the new war machine, and ultimately resulted in an *impasse.*

(*d*) Tanks in Action, September, 1916.

The first party of the men of the Heavy Brigade Machine Gun Corps crossed to France on 13 August, 1916. Two sections of tanks followed on the 15th, and by the end of the month two companies were concentrated in the training centre at Yvrench. The tanks went into action for the first time on 15 September. Forty-nine were employed, but only thirty-two reached their starting point. Five of these were ditched and nine broke down from mechanical trouble, while of the remaining eighteen, nine did not catch up with the infantry. Thenceforward the tanks were used in twos and threes as machine-gun destroyers in a series of small experimental actions against special strong points until the weather conditions ended the fighting season. At Gaudecourt (25 September) they co-operated effectively with a low flying aeroplane. At Thiepval they confirmed, by their effectiveness in a surprise attack without artillery preparation, the contentions of those who urged that where tanks were to be employed, the ground over which they were to operate should not first have been blasted by our own artillery preparation.

Calls for further shipments of tanks were received from France during this period of experimental fighting. The experience which had been gained in these engagements encouraged the high hopes entertained of them, in spite of the dfficulties inherent in the employment of an absolutely new arm. The crews engaged were almost without training. The tanks were almost in embryo as regards design. Everything hitherto had been done on the basis of theoretical hypothesis. The ground over which the tanks were fought was almost impassable. Yet this first engagement was regarded as establishing the likelihood that the new weapon would become a reliable arm.

II. Schemes for Extensive Production.

(a) PROGRAMME FOR ONE THOUSAND MORE TANKS.

The Army Council enquired on 26 September whether 1,000 additional tanks could be ready by 1 March, 1917. The diversion of energies from manufacture of complete machines to that of spare parts had, however, resulted in a dwindling of output. It was entirely beyond the capacity of the department to produce the number required within the time named. The War Office therefore cancelled its request for an additional 1,000 tanks on 30 September.

There were then 40 nearing completion. These were to be of the same design as those already issued (Mark I). There were 100 more on order. They were to be of the same design with certain modifications to the roof, gun-mountings, tracks and mechanism which had been arrived at by experience of the recent fighting and which were to be introduced as soon as possible without hampering output (Marks II and III). It was then understood that these would begin to materialise about the second week in November at the rate of 20 per week, and production was expected to increase to 40 per week on or about 1 January, 1917.

The War Office had sanctioned a continuation order of the existing design to enable the full output to be maintained until machines of the new types were ready to take their place, and 600 were accordingly ordered with a view to maintaining a continuous flow of supply. Delivery on these orders was promised to start about January, working up to 40 per week. It did not start in fact until April. Meanwhile, the Russian, French and Belgian Governments were asking for tanks of British manufacture. Colonel Stern maintained that 1,000 machines could be produced by the end of June, if supply were allowed to be continuous, and that it was necessary to decide whether a subsequent output of 80 per week would meet the British requirements. He contended, furthermore, that in view of the enquiries from the Allies, capacity for production should be immediately increased to 150 tanks per week. The needs of the British forces necessarily came first, and it was not until 1918 that issues of tanks were actually made to the Allies.

On 14 October, 1917, the Army Council renewed its demand for 1,000 tanks additional to the 250 previously ordered. It was considered that 3,000 additional workers, of whom 1,000 to 1,400 might be women, would be required for this programme, and that the recall of 200 specially skilled men from the colours was essential to enable Messrs. Daimler to supply the requisite number of engines. The supply authorities anticipated no difficulty in securing this necessary labour. They considered that an additional 1,000 tanks for the Allies could be manufactured at the same rate per week with slight increase of labour, starting two or three months later. Tentative enquiries were made as to the practicability of manufacturing tanks on the Clyde and at Belfast. The output of engines seemed likely to prove a limiting factor; but the department believed there was every prospect that

additional sources of supply, beyond the Daimler Company, could be devised in consultation with other departments concerned. The cost of additional plant for increasing output to 40 per week was estimated at about £200,000, and for additional erecting shops at from £60,000 to £80,000. In order to increase output from 40 to 80 tanks per week, another 2,000 workers would be required, many of whom might be women, and the additional plant was estimated to cost £100,000, the sum being dependent on what arrangements could be made for increasing the supply of engines.

The supply of 6-pdr. guns beyond 40 per week required an additional capital expenditure of £15,000 for every 10 additional guns and mountings, if the additional supply was to be obtained from Messrs. Armstrong Whitworth.

(*b*) Concurrent Administrative Changes.

The decision to enter upon an extensive programme of tank supply raised also the problem of further administrative developments.

With the actual adoption of tanks into service, there began a series of departmental changes which tended to curtail the autonomy of the supply authority established in January, 1916. The first point which arose for settlement concerned procedure relating to demand. The War Office, the Heavy Brigade Machine Gun Corps and G.H.Q., France, each formulated their requirements separately. Verbal sanction had been given in June, 1915, by Mr. Lloyd George for the provision of 50 gun-carrying tanks in anticipation of the War Office demand. The demand was not received until 12 months later. This raised the question of procedure with regard to demands arising from sources other than the War Office. The Army Council requested (16 August, 1916) that as the Heavy Brigade Machine Gun Corps had assumed a definite shape and the section had commenced to take the field, the procedure for obtaining armament stores for tanks should be brought into line with that already in force in the service, *i.e.*, the Commanding Officer Heavy Brigade Machine Gun Corps should no longer demand direct on the Tank Supply Department but through the Director of Artillery. It was agreed that demands for tank stores, other than guns, etc., were to be forwarded to the Tank Supply Department through the usual channels, although issue should take place directly from the stores controlled by the department. A further effort was made to curtail the department's extraordinary powers in regard to the design, inspection and transport of tanks, and to bring about the greater subdivision of labour and allocation of responsibility which the army favoured. The Army Council, on 4 October, 1916, recommended that, in future, all tanks with their equipment, accessories and spares, should be manufactured and tested by the supply department; but that representatives of the Heavy Brigade, the War Office and, if desired, the General Staff, G.H.Q., France, should be present at the trials, the scope of which should be defined by the War Office. All tank equipments and spares should be handed over by the Ministry of Munitions

to the Heavy Brigade either for training purposes at home, or for field service in France. Depôts for material should be formed under the supervision of the Heavy Section in France on lines similar to the aircraft parks. Finally, tanks and equipment, passed for issue and not required for immediate use, should be retained in store by the supply department. The Army Council at the same time particularly requested that they should be consulted regarding specifications of tanks before any designs were approved, and that no change should be made in specifications without reference to them. Shortly afterwards they desired that when once tank tests were completed satisfactorily and the tanks were handed over to O.C. Heavy Brigade Machine Gun Corps, further responsibility for despatch to destination or for the movement or equipment of personnel should be removed from the Director of the Tank Supply Department.

The recommendations with regard to the testing, storing and disposal of tanks were readily adopted, but the suggested changes in responsibility for design and transport were opposed. They brought into issue the independent status granted to the Tank Supply Department by its charter and, so far as responsibility for design was concerned, were also contrary to the general decision given on 27 November, 1915, that the transfer to the Ministry of Munitions of responsibility for design left to the War Office only the functions of fixing the requirements of the army regarding the nature and amount of munitions, of allocating them among the forces and of storing and distributing them. The testing and transport of tanks had hitherto been carried out by the Tank Supply Department through officers and men of Squadron 20, by whom an embarkation station was maintained at Portsmouth and a receiving station at Havre. It was urged by the department that the transportation of tanks needed peculiar skill; that it involved dismantling and reassembling the machines and moving them under their own power some five or six times during the journey from the manufacturers' works to headquarters in France. A special organisation had been built up to deal with the problem.

In the meantime, the supply organisation was itself undergoing a certain reconstitution to meet the development of its task. Experience had proved that there were not enough firms available with adequate capacity for producing large numbers of tanks complete in all their details. The manufacture of certain components required to be separately developed by the department, which would have to supply such items to the main tank erectors. The rapid extension of the headquarters staff of the department, which was necessary to meet this new phase of production, very soon rendered it necessary to find more suitable accommodation. The secrecy with which the work of the department had hitherto been conducted contributed, no doubt, to ignorance of its requirements in the matter of accommodation. After some difficulty, new quarters were found at No. 17 Cockspur Street, whither the department moved in October, 1916, at the same time taking the name of Mechanical Warfare Supply Department. Under the new arrangement, Lieut.-Colonel A. G. Stern was Director

General, Mr. P. Dale Bussel and Captain Holden were Deputy Directors General, Mr. E. H. Tennyson d'Eyncourt acted as Chief Technical Adviser, and the Hon. Sir Charles A. Parsons, K.C.B., as Technical Adviser. Mr. W. A. Tritton and Major W. G. Wilson were appointed, respectively, Director of Construction and Director of Engineering; but the internal organisation of the department was still inchoate, and included no supply branch proper. Moreover, its independent methods began to bring it into conflict with other departments of the Ministry whose control over facilities and materials was increasing rapidly with the economic pressure of the war. During the remainder of the year the internal organisation of the department continued to expand to meet its increasing duties. Distinct sections were organised to deal with finance, stores and statistics. An adviser on petrol engines was appointed and a separate branch for the supply of equipment was established. Inspection of engines was organised under an officer who later became responsible for engine production, and on Christmas Day the first head was appointed to a definite inspection department. A chief draughtsman and a director of design were added to the staff. Squadron 20, which now numbered 160 ratings, continued to serve as the Inspection and Transport Section. A detachment of ratings under one or more officers was placed at the works where the machines were being built. The first fully equipped testing station was opened at Oldbury on 28 September, 1916, to test and handle all machines produced by the Metropolitan Carriage Works at Oldbury and Saltley. It was soon found that the work of testing had to be augmented by provision for adjustments. The squadron therefore, in addition to its duties of testing machines, developed a fully equipped field workshop. Its ratings were divided into testing crews and repair men, the latter putting right defects which were discovered during running tests. Stores were also opened at Oldbury in November under the control of the squadron. In face of the revised arrangement within the Mechanical Warfare Supply Department, which thus included definite organisations concerned with design and transport, the Army Council persisted in its demand to control these two functions.

The means to be used for translating the recent experience in the field into the work of design, supply and training was of peculiarly pressing importance. While the performance of the first machines in the field had shown the possibilities of the new arm, it had also proved that certain mechanical improvements were necessary in order to give the machine value as a fighting unit. Between the time when the War Office renewed its demand for 1,000 tanks and the meeting of a conference which finally determined the general type of tank required (14 October to 23 November), discussions took place with the General Staff in France with a view to incorporating improvements from experience gained in the field. A further step towards close contact was secured by the appointment of General Anley to the command of the Heavy Brigade Machine Gun Corps in England, and the establishment of his offices near those of the Mechanical Warfare Supply Department. At the same time Colonel Elles was appointed to command in France and took over on 29 September. A large central depôt

and repairing shop were allocated to his command. The personnel of the Tank Corps was withdrawn to the Bermicourt area, where this "veteran" tank personnel became available as instructors. In England there was a headquarters staff directly under the War Office, to administer the corps as a whole. It was responsible for the provision of men, for supplies of "technical material," for the preliminary training of units and for the maintenance of units in France as regards men, machines, material and spare parts.

It was arranged that spare parts and equipment should be directly requisitioned for France by General Anley, and shipped direct to the headquarters in France by the Mechanical Warfare Supply Department.

Attempts were made at various conferences (22, 23, 30 November) to overcome the impasse as to responsibility for design and transport of tanks which arose at the very commencement of the activities of the new department, and which if unsolved could not but affect the success of the new arm in the service. At the first of these it was agreed that conferences should be held at regular intervals or when necessary between members of the War Office, G.H.Q., France, and the Ministry of Munitions, with a view to saving time and unnecessary correspondence, and in order that personal opinions might be exchanged, so that all interested might be kept informed of progress and developments.

On the following day a meeting was held at the Mechanical Warfare Supply Department at which the results of discussions to date were defined. It was decided that a conference should be held in London whenever any important question connected with design, output or dates of delivery should arise, and that the following should attend :—Lieut.-Colonel Stern, General Anley, O.C. Heavy Brigade, England; Colonel Elles, O.C. Heavy Brigade, France; representatives of the War Office; representatives of the General Staff, France; the technical advisers of the Mechanical Warfare Supply Department. It was resolved that a meeting might be convened by any of these representatives under the chairmanship of Colonel Stern, who would prepare the agenda and keep the records, and to whom anyone who wished to raise any question should send particulars. A technical liaison officer was appointed between General Anley, Colonel Elles and Colonel Stern.

It was thus intended to establish closer co-operation while maintaining the independent status of the Mechanical Warfare Supply Department; but the Army Council were still anxious to increase their control over design and transport. On 30 November, they put forward suggestions as to "the best means of ensuring that the design of tanks is developed in conformity with the tactical employment of those engines." They proposed that a committee should meet monthly to deal with questions of tank design, and should be composed of G.O.C. Heavy Brigade Machine Gun Corps; the technical Staff Officer, Headquarters Heavy Section Machine Gun Corps; representatives of G.H.Q., France, of the Master-General of Ordnance and of the Quartermaster General; the director

of the supply department, Mr. Tennyson d'Eyncourt, Sir C. Parsons, and also associate members to be nominated by the Ministry of Munitions. The secretary should be a member of the staff of the G.O.C. Heavy Brigade Machine Gun Corps, and the senior military member of the committee should preside. The secretary would keep the departments of the Master-General of Ordnance and the Quarter-Master-General informed on all questions of design and supply affecting their branches, and make arrangements as between the Quarter-Master-General and the supply department for the transportation of all tanks and tank spares, special vehicles and machinery. This new proposal thus tended to place the balance of control over questions of design with the military, rather than the supply, authority and to remove from the Mechanical Warfare Supply Department its duties in regard to transport. No immediate decision was made, and the end of the year found the War Office and the Mechanical Warfare Supply Department in disagreement as to fundamental questions of procedure, while the administrative and fighting organisations also lacked co-ordination. General Elles thus summarised the position in a report[1] of 21 December, 1916:—

> "In France, the fighting organisation is under a junior officer who, *faute de mieux,* has become responsible for initiating all important questions of policy, organisation, design and personnel through G.H.Q., France, and thence through five different branches at the War Office. In England, administrative and training organisation are under a senior officer, located 130 miles from the War Office, with a junior officer (staff captain) in London to deal with the five branches above mentioned. The system is working now because headquarters in France have been free from the questions of operations for most of the last six weeks, and have therefore, been in a position to deal imperfectly and at a distance with the larger aspects of the whole matter. In effect the tail in France is trying to wag a very distant and headless dog in England. We have had one check already in the matter of the increased weight of Mark IV which, it is possible, may have serious results as regards transportation."

(c) DIFFICULTIES AND DELAYS IN PRODUCTION.

While the administrative problem still awaited solution, formidable practical difficulties had to be met in the interests of production. The supply of engines was a source of considerable difficulty. The first makers of tank engines proper were Messrs. Daimler, with whom 275 were on order by 25 July, 1916. The Daimler engine had been developed by Messrs. Foster for large tractor work, and was the power-unit used on the early experimental tractors, which were forerunners of "Mother Tank." The difficulties which were experienced in the boggy soil of Flanders in the autumn of 1916 proved this engine inadequate to its task. The Daimler Company was itself unable to produce similar engines in larger sizes. It was decided, therefore,

[1] Quoted in the *Daily Telegraph,* 11 September, 1919

in October, 1916, to adopt a new type of engine built under the patents of Mr. Ricardo. The design was an adaptation of the Ricardo super-charging engine originally evolved for the R.N.A.S. Detailed design of this engine, which had to have the same width and overall length as the Daimler engine, was commenced in November. An order was placed with a single firm for 20 engines. During this month it was decided to increase the orders then placed to 700. Four other makers of engines accepted orders. The five firms met on 4 December, 1916, at the offices of the supply department to discuss measures for collaboration and the pooling of resources. At this meeting it was decided that some firms should undertake production in bulk of parts required by all firms. This conference was, in effect, the inaugural meeting of a "Tank Builders" group, which, under the chairmanship of Mr. Charles Day, held periodical meetings in Manchester to discuss difficulties in production as they arose from time to time. The Ricardo type of engine, in 100, 225, and 300 h.p. sizes, subsequently became the standard engine for tank work. The output of the five firms was not, however, immediately available for tanks since their capacity was required at this time for aircraft.

An enormous increase in the demand for ammunition for the extended programme of tank supply also occasioned grave anxiety, and the production of the heavier 6-pdr. armament threatened to encroach upon concurrent naval and military demands for heavy guns and repairs, the provision of the necessary steel being a special difficulty.

Despite these problems and the difficulty experienced in obtaining an adequate supply of labour and material to meet existing demands, the supply authorities were anxious to make provision for an even greater production, and on 30 October, 1916, Mr. Montagu wrote to Mr. Lloyd George,[1] "Stern wants an order for a second thousand tanks. He convinces me he ought to have them. They are far better than infantry. He wants to assure manufacturers of orders. They will, of course, be of new and improved design." On the other hand, the Army Council hesitated to formulate schemes involving such enormous quantities of labour, plant and material while the capacity of the supply department to meet the existing programme was not yet established. The department was asked (4 November, 1916) whether twelve tanks could be ready in this country not later than 15 November, so that they could reach Egypt by 15 December. Colonel Stern replied that the existing type was unsuited to the Egyptian climate, and that the alterations necessary would make it impossible for the tanks to be ready within a reasonable period. Nine tanks only were available for immediate despatch, and these were old experimental machines instead of new ones. Eight of these were shipped to Egypt on 23 November, the ninth being retained for experiments connected with a new type of rollers. In spite of the defects of these machines, it was subsequently reported that they had proved themselves of the greatest value in the Egyptian theatre of operations.

[1] D.M.R.S. 341.

A definite programme for 1,000 tanks only was formulated by General Davidson at the meeting on 23 November. It was agreed that they should be in the proportion of one male to two female tanks, and that the Lewis gun should be substituted for the Hotchkiss machine gun. There were then 70 machines in France. No figures were available of deliveries of the other 80 Mark I machines. Colonel Stern undertook that 50 Mark II tanks should be ready by the beginning of January. 50 Mark III tanks were to be ready by the beginning of February. They were to be of the same design as Mark II, but with thicker armour. The new type of tank (Mark IV) was to be produced from 7 February till the end of May, starting at the rate of 20 per week. This was an improved Mark I with armour of a special steel, fixed sponsons which could be pushed in for railway transport, no tail, reduced weight and improved tracks, while danger from fire was reduced by placing the petrol tank behind and outside the machine. It was understood that 300 would be ready in May, and it was important to accelerate the output of Mark IV tanks in order to get as many as possible in France for active operations in that month.

A conference on tanks was held at the War Office in the afternoon of the same day (23 November, 1916). Sir Douglas Haig was present and it was generally agreed that tanks were required in as large numbers as possible, that it was important to get as many as possible before May, and that while it was very important to consider and adopt improvements in design from time to time, almost any design was likely to be better than no tank. It was, however, highly desirable that no other supply should be interfered with at least without the knowledge of the G.H.Q. In accordance with these decisions the Minister (Mr. Montagu) gave instructions that orders for steel for tanks should be treated as most urgent war work and given first-class priority. Subsequently, in December, 1916, the Minister confirmed the following estimates of output. Between 1 January and 7 February, 1917, 100 tanks would be available, to be followed by 80 more by the end of February, and an additional 80 in each of the months of March, April and May, thus making a total of 420 by 31 May. Thereafter delivery was to be at the rate of 30 weekly with a gradual increase until August, 1917, when output would be at the rate of 60 per week. At the same time, the Army Council also pressed for an assurance that this manufacturing programme would not make it necessary to put forward any request for any additional operatives. This guarantee the Minister declared himself unable to give. Such an assurance had not been given by him in connection with the supply of any munition.

In the meantime, during the winter of 1916–1917, owing to wastage in the field and to the defects in the track-roller supplied with Mark I machines, there were not even enough tanks for the training scheme in France nor for the big training centre established at Wool. The unsatisfactory position of supply and the urgent need for a more effectual arrangement of administrative procedure gave rise to far-reaching changes in the following year.

CHAPTER IV.

CHANGES IN POLICY AND ORGANISATION, 1917.[1]

I. Introductory.

The pioneers in tank supply had condemned the tactics which had employed the new engines of war over shelled ground and in small groups of twos and threes. They contended for the "big idea" and the "break through" by means of a mechanical army; while military authorities were disappointed by the comparative failure of the Mark I tank as tested under the disadvantageous conditions of September, 1916. The War Office accordingly awaited the results of further experience in the field which, until after the battle of Cambrai, were of an uncertain nature.

Even after the battle of Arras, the tank was regarded by many as an experiment, which after the first success of its original surprise, had practically no future. Pending a more definite decision as to the utility of the new arm, the conflicting proposals which were made at the end of 1916 for strengthening the control of the War Office in regard to tanks, remained in abeyance, until renewed experience in the field and considerable delays in output at home gave rise to further changes in procedure.

II. New Methods of Supply.

(*a*) Re-organisation of the Mechanical Warfare Supply Department.

Meanwhile, the department was able to set its house in order. A transport section was created and was manned by Squadron 20, while a special officer (Captain A. C. Bussel) was appointed to organise railway and sea transport in close co-operation with the departments of the War Office concerned. The transport section supervised the transportation of tanks, spares, etc., not only within Great Britain, but right through to G.H.Q., France. Squadron 20 maintained a large establishment of lorries and cars at their various stations and also at works where tank parts were manufactured, in order to speed up production.

The experimental section of the department also became a separately organised and independently equipped unit, with officers and ratings lent by Squadron 20 to assist in its work. It had its chief experimental ground at Oldbury. There the earliest new development of the year—the gun-carrying tank—was tried successfully. Another experimental ground was subsequently established at Cricklewood. Experiments were also being carried out independently at the workshops at Wool and in France where devices

[1] Based mainly upon Mr. Churchill's papers, Memoranda for 1917, *penes* Sir Albert Stern, a departmental history of the Mechanical Warfare Supply Department (Hist. Rec./H/1940/6), papers relating to Tank Programmes (D.M.R.S., 341 A, 341 A1) and "Weekly Tank Notes."

were evolved to meet the needs revealed by experience in battle. Projects for further development of experimental facilities under the Mechanical Warfare Supply Department met with little support. Thus in March, 1917, the Minister rejected a scheme for utilising the workshops at Lincoln under Sir William Tritton for experimental work alone. The future of tanks was still considered too uncertain to justify this development, and nothing further was done in this direction until later in the year, when Mr. Churchill recognised the need for intensive experimental work to ensure adequate timely supply.

A contracts section was formed in February, 1917, when Mr. Dale Bussel, who had controlled the contract arrangements since his first appointment on the Admiralty Landships Committee, relinquished his position as Deputy Director of the Mechanical Warfare Supply Department. A finance section had been established in the department at the end of 1916. These sections were subject respectively to the control of the Contracts Department and the Finance Department of the Ministry, which had representatives in them ; but they were also under the Director General of the Mechanical Warfare Supply Department, in whom was vested an overriding discretionary power. Although this system differed from the general procedure of the Ministry, it proved successful in ensuring uniformity of policy while leaving the supply officer considerable autonomy. The increased demands at the end of 1916 led to enquiries as to the possibilities of tank erection elsewhere than at the two factories which had carried out the pioneer work of manufacture. Arrangements were made for the manufacture of 400 machines in Scotland. Two armament firms (the Coventry Ordnance Works, Glasgow, and Armstrong Whitworth and Company, Ltd., of Newcastle-on-Tyne) were added to the list of contractors for tank erection, while Marks II and III were in course of production and Mark IV was under consideration. A firm of agricultural machinery and boiler makers (Messrs. Marshall, Sons and Company, Gainsborough), were added for the production of Mark IV.

A components section was created within the department to deal with the increasing number of firms engaged in the manufacture of tank parts. It had been the practice of firms engaged on the erection of tanks to place direct contracts for these small parts. Overlapping resulted and the limited facilities for production were overtaxed. The department accordingly undertook to provide contractors with such components as steel castings, links and gear-boxes, as well as armour plate and engines. In consequence it became necessary to arrange for inspection of these parts during manufacture. The duties of inspection were allocated to a small body of resident and divisional inspectors in January, 1917. Inspection, which consisted in proof of armour plates, examination of parts to gauges and supervision of erection, was carried out at the works of sub-contractors as well as main contractors, and in certain cases also at stores, to secure interchangeability of parts. The inspection staff was organised at six large centres, Birmingham, Lincoln, Leeds, Newcastle, Glasgow and Manchester. Divisional inspectors communicated with each other regularly

regarding local manufacturing facilities, and advised contractors as to how best they could obtain required parts, or labour, or higher priority. This combination of the duties of inspection with responsibility for progress did not prove entirely satisfactory in its results.

A testing station similar to the one at Oldbury was opened by Squadron 20 at Lincoln on 13 January, 1917, to deal with the tanks produced by Messrs. Foster and Company. Another was opened at Scotstoun, Glasgow, in June, for testing tanks produced by the Coventry Ordnance Works, Messrs. William Beardmore, Ltd., and Messrs. Mirlees Watson and Company, Ltd. A small station was opened in the summer of 1917, at Gateshead, to test machines produced by Messrs. Armstrong Whitworth and Company. These stations were closed in August, 1918, when a central testing station was established at Newbury. Squadron 20 was responsible for the running tests of the completed machines which they took over from the inspection staff and transported to the Heavy Brigade Machine Gun Corps whether in England or in France. Thus they formed a link between the inspection staff and the army. The existence of this link tended to weaken the efficiency of inspection.

The growth in the activities and responsibilities of the department and particularly the increasing tasks of securing and training labour and of bringing new sources of supply up to the productive stage now rendered imperative a decentralisation of authority within the department. For this purpose Colonel Stern summoned to his assistance in January, 1917, Mr., afterwards Sir Percival, Perry, the managing director of Messrs. The Ford Company (Europe) Ltd., who had already been investigating the practicability of purchasing American engines for the department. He prepared a " lay-out " of the department in 13 sections on the lines of a commercial undertaking. Orders were negotiated by the supply officers and placed through a single contracts section which acted as a common service. The branches dealing with design, supply and inspection reported to the Director General, and were inter-dependent. The supply branch dealt with the negotiation and administration of contracts, but had no outside officers of its own. A production officer was appointed in February, 1917, but the supply branch was entirely dependent on the inspection branch for information regarding makers' progress and sources of supply. Standard parts were ordered in large quantities and either stored at Leicester or held as stock for use at contractors works. Armour plates were obtained in advance and bonded in two places, Birmingham and Glasgow ; optical stores were all inspected in London and then sent to Leicester. The design branch controlled completely all points in connection with drawings even in transactions with contractors. It laid down specifications and communicated them to contractors while the inspection branch was responsible for the maintenance of the standard set.

A small section for purchasing equipment was created at the end of 1916. A list of accessories which were to be supplied with each tank had already been compiled by this time. A schedule of spare parts was laid down by the military authorities in January, 1917.

Thus developed Army Form G 1098/295 giving details of equipment for each mark of tank. The equipment for Mark IV was the standard eventually adopted, and it varied but little for each class of machine. The various items were supplied by four departments—the Army Ordnance Department, the Mechanical Transport Department, the Army Medical Department and the Mechanical Warfare Supply Department. In some instances, absence of a definite responsibility for collecting and assembling these items caused delays in France. In January, 1917, this hampered training and threatened to affect operations. It was, therefore, arranged that the Mechanical Warfare Supply Department, which provided the greater number of the items, should become responsible for the collection of all stores other than certain ordnance stores.

(*b*) THE PROGRESS OF SUPPLY, JANUARY–APRIL, 1917.

One of the difficulties which confronted the reorganised department was that there was no certainty as to what were the requirements of the forces in regard to numbers or types. While in January, 1917, the only kind of tank formally demanded was Mark IV, General Davidson had stated at the conference of 23 November, 1916, that light tanks would be required. The order for gun-carrying tanks sanctioned by Mr. Lloyd George had not been confirmed by the War Office. The enquiries made as to the possibility of manufacture for the Allies had not materialised. On 11 February, 1917, Sir Douglas Haig stated that an organisation had been provided to deal with 1,000 heavy tanks besides the machines for training, but that the provision of a light tank was for later decision. A preliminary trial of the light tank had, however, justified high expectations and large orders for this new type were anticipated.

Deliveries of Marks II and III were completed by the end of February, 1917. Fifty of these were despatched to Wool and fifty to France, for training purposes. By 17 February, when individual courses came to an end and unit training began, the Heavy Brigade Machine Gun Corps was about 9,000 strong. The authorities had decided that three brigades, of three battalions each, should be formed. Each battalion was to be equipped with seventy-two machines and to consist of four fighting sections, a headquarters section and a battalion workshop. The War Office accordingly stated its requirements as follows:—

(*a*) Mark IV: 648 for equipment, 352 for first reinforcements, (*b*) light or chaser tanks; as many as possible up to 200 by the end of July. Mark IV machines to have priority till June; then the first hundred of the light or "chaser" tanks. This latter type required two Tylor engines per machine. 300 of these engines were expected to be at the disposal of the department by the end of June, allowing for the production of 130 light machines with 25 per cent. spare engines. Orders were placed for 200 of the chaser tanks, but output was not expected for three months.

The output of Mark IV, which was to have begun on 7 February, was delayed. Manufacturing estimates were revised and the arrears

for March, April and May, amounted to 200 machines. The army in France was compelled to use training tanks in action during the battle of Arras. On 21 March, 1917, Colonel Stern attributed the failure to reach the estimated output to lack of necessary labour, to a ruling which gave priority to aircraft over tanks, and to the break in the continuity of production which arose from changes in design, rendered necessary by the experience gained in the actual use of the tank as a fighting machine. The changes in design which were determined on 23 November, 1916, involved alterations in drawings which were completed within six weeks. Preparations for production in bulk of the new type of machine occupied the following ten weeks. Some relief to the labour position was expected from the employment of military working parties, a course already pursued in the autumn of 1916. Although shortage of labour was one of the causes to which the delay was attributed, it should, however, be noted that all demands for labour had been met as they were put forward by the contractors. The ruling that aircraft engines should have priority over those for tanks was given by the Commander-in-Chief on 11 February, *i.e.*, at a date after the output of Mark IV should have begun. There was, however, considerable danger that the arrangements which had been made for the manufacture of 400 machines in Scotland would be seriously delayed in consequence of an order which had been placed by the Admiralty for the construction of 70 standard ships within seven months. Renewed difficulty was also experienced in regard to the supply of spare parts, the actual demands for which had in some cases exceeded the previous military estimates by six times, and threatened to occupy the whole capacity for producing new machines if they continued proportionately.

Whatever weight these various factors had in turning the balance against speedy output, there can be no doubt that the tardiness of development within the supply department itself was a contributory cause to delay. The practical difficulties of initiating manufacture of an entirely new weapon of war were also very considerable. These were particularly apparent in the supply of steel castings. The high percentage of scrap castings discovered when links were being machined proved that the British steelfounder was then unable to produce homogeneous castings in continuity. In the first six months of 1917 from 33 to 40 per cent. of the castings manufactured were rejected in consequence of blowholes and segregation of sulphur and phosphorus at the parts of the link where soundness was particularly essential. The department, therefore, initiated a lengthy series of experiments whereby the tensile strength was raised by heat treatment from 28 to 40 tons per square inch without detriment to output. It is contended that these experiments created a new era in steel production. In the meantime, the production of track links proved a limiting factor in the output of tanks, and contributed considerably to the accumulation of arrears, since it was always some six months from the time of placing a contract before a new founder could produce satisfactory links in considerable quantities.

One of the great difficulties in making cast steel links was, that owing to their small size, only the first part of the ladle could be used. The remaining 40 per cent. of molten metal could be used only for much heavier castings. There were not many firms which could manufacture the small link castings of 14 lb. each and also the heavier steel castings which weighed up to 180 lb. each. From March, 1917, the responsibility for securing adequate facilities for these castings was transferred to the section of the Machine Tool Department which had been established in the previous September to co-ordinate supply of castings for all munition purposes.

By the beginning of April, the First Brigade of the Heavy Machine Gun (Tank) Corps in France, was preparing for action and was finding itself considerably hampered by difficulties of transport. "Every tin of petrol, every round of ammunition had to be carried by hand from railhead."[1] It was calculated that had supply tanks been available, each such machine would have saved a carrying party of 200 men. The tanks went up the line on the night of 8-9 April and remained in action until 3 May. The output of Mark IV machines was then in progress. It was estimated (18 April, 1917) that 80 would be delivered in April, 100 in May and 120 in June. Nineteen Mark IV machines were shipped to France by the middle of April. Within a few days of their arrival in France a board of officers reported, that as received, they were unfit for fighting and that the whole position pointed to lack of adequate inspection at home. The report was concerned chiefly with the Lewis gun mounting but criticised adversely also some sixteen other points. The experts in France were also dissatisfied because they thought they were left out of consideration in questions of tank design. The Commandant of the training camp at home also complained that careless inspection was responsible for many difficulties experienced. The unsatisfactory position was intensified by lack of understanding between the department and the War Office. Colonel Stern thereupon urged that a central body should be established to give authoritative decisions on tank questions from the military point of view and that the supply department should have its own workshops in France and at Wool. Thus the questions of control which had been in abeyance since the previous year were once again revived. The Commander-in-Chief requested simultaneously that since the importance of tanks was firmly established, a special department of the War Office should be established to deal with them.

III. Attempts to Centralise Control, May–October, 1917.

(*a*) Establishment of the First War Office Tank Committee, May, 1917.

The need for some central body responsible for correlating the experience in the field with practice in the workshops and with the general development of programmes for munitions supply as a whole

[1] Major Clough Williams-Ellis. *The Story of the Victorious Tanks* (*Daily Telegraph*, 12 September, 1919).

was thus generally admitted. During the next six months (May-October, 1917) various attempts were made to establish a body which would meet the circumstances of the case. The first step taken was the creation of a War Office Tank Committee in May, 1917. This Committee was to formulate specifications which the design section of the Mechanical Warfare Supply Department should put into effect, to approve designs before manufacture began and to direct field trials of new machines. The outstanding question of responsibility for transportation was to be decided by this Committee. It was to consist of a president, not below the rank of Major-General, with experience of recent fighting in France, the Master-General of Ordnance representing the War Office, a General representing the Heavy Branch Machine Gun Corps and two representatives of the Ministry of Munitions. Major-General Capper was appointed President of the Committee and was also in command of the Tank Corps, Lieut.-Colonel Stern and Sir E. Tennyson d'Eyncourt represented the Ministry. While the question of procedure in regard to design was thus temporarily settled, the control of transport remained open for settlement, and a reorganisation in regard to the administration of inspection and contracts was also necessitated by the establishment of the tank as a permanent service store. The Minister (Dr. Addison) ruled that, since tanks had become an established item of supply, there was no ground for the responsibility for their inspection to be separate from that relating to other munitions, but that it should comply with the general principle whereby inspection was independent of supply. It was, however, found impracticable to make any immediate change in this respect. The War Office Tank Committee maintained that any alteration in the organisation of production, inspection and delivery should be postponed until the end of the year, in view of the strong representations of the supply representatives that any immediate change would seriously endanger output during the summer months. A remedy was needed because the faulty inspection of tanks had been the subject of complaint from all quarters; but the organisation of the supply department lacked the differentiations of functions and allocation of duties which would have rendered possible the immediate application of a remedy. The new Tank Committee therefore sought to secure partial relief by recommending that a high official with great experience in the Inspection Department of the Ministry should assist and advise the Mechanical Warfare Supply Department, and that officers of the Tank Corps should take charge of the running trials of tanks at the various testing grounds before shipment. The contracts and finance of the Mechanical Warfare Supply Department were brought under the central authority; but this gave rise to emphatic protests from contractors against the reopening of negotiated terms.

(b) THE 1918 TANK PROGRAMME.

Future policy in regard to expanding the Tank Corps and the programme for the establishment of tanks in France during the year 1918 were the subject of discussion at conferences which were held at Lincoln and at the War Office, 29 April–1 May, 1917.

A very heavy (60 ton) tank had been completed at Oldbury but was not likely to materialize in the current year's output. It was, therefore, omitted from the estimates, but it caused confusion in nomenclature. The Mark IV tank was subsequently called "heavy" and the chaser or light-tanks were all called "medium." It was understood that the first gun-carrying tank would be ready on 5 May, and that delivery would be at the rate of 4 per week from the middle of June. Two hundred chaser tanks had been ordered on 21 March. Fifty Medium Mark A, or "Whippet," tanks were ordered for the earliest possible delivery. It was decided to discard the Lewis guns which had been adopted in the recent issues and to restore the Hotchkiss machine gun with pistol grip for all tanks. Heavy tanks were to be armed with Q.F. guns only, medium tanks with machine guns, and a 2 or 3-pdr. gun for anti-tank use. At a later date, the female heavy tank was reintroduced in the proportion of two to every three male tanks of this type.

The workshops in France, benefiting by experience gained in the battle of Arras, were converting 12 machines of Marks I and II into supply tanks for the battle of Messines, which was fought between 5 and 12 June. In this action it was established that the German armour-piercing bullets proved powerless against the modified plate of Mark IV tank, but the tanks themselves played no great part in this battle. In spite of limited experience gained with the new types, Sir Douglas Haig, however, recommended that orders should be placed immediately to equip and maintain 9 battalions of medium tanks as well as 9 battalions of heavy tanks and he ruled in regard to priority, that tanks should rank after aeroplanes, road mechanical transport and guns. He defined the specifications for the new types of heavy and medium tanks. He also asked that the production of tanks suitable for supply and for signalling should be considered and that certain defects in the existing Mark IV should be remedied immediately. Provisional orders were accordingly given, in respect of the Medium Mark B tank, for 3,600 Tylor 45 h.p. engines (2 per tank) at a rate of 600 per month, beginning in September, including the 400 being supplied for the 200 Mark A medium tanks already ordered. For the Mark V heavy tanks 1,800 Ricardo 150 h.p. 6-cylinder engines were ordered at a rate of 300 per month, beginning in February, 1918. All the parts for Mark IV machines had been ordered by April, 1917, and orders were then placed for the production of Mark V up to 200 machines, whereof the output was expected to begin six months later.

(c) Establishment of a Tank Directorate within the War Office, August, 1917.

The military and civilian members of the Tank Committee which had been established in May, 1917, did not work in harmony together. The attempts made by the Committee to control working design as well as general specification proved impracticable. The representatives of the Ministry found themselves outvoted and considered that insufficient regard was paid to their exceptional experience in tank and design production. They also maintained that the absence from the

Committee of any representatives concerned with the actual fighting of the new machine, prevented the supply and design authority from gaining direct touch with conditions in the field. They accordingly discontinued their attendance at the meetings of the Committee. A separate directorate to deal with questions relating to tanks was established at the War Office under the control of General Capper. The new department was responsible for formulating requirements for tanks, controlling their use and supplying and training their personnel. Communication between the personnel in the training camps and in the field with the authorities responsible for design and supply thus became even less direct than before.

The Munitions Council which Mr. Churchill established in August, 1917, brought the Mechanical Warfare Supply Department within a group of departments which was placed under the direction of Sir Arthur Duckham. A conference which was held at the Ministry of Munitions under the chairmanship of the Minister on 29 September, 1917, revealed the *impasse* then existing between the War Office and the Director General of the Mechanical Warfare Supply Department, whereby communication was practically interrupted, so that the War Office was ignorant of what the supply department could do and the latter was uncertain of what was required from it. There were considerable divergencies between the requirements laid down by the War Office and the output for which the department had been able to arrange. Thus the War Office had asked for 1,000 Mark IV machines, but the supply department had arranged for the manufacture of 1,400 and was accordingly charged with over-production. The army required by 1 March, 1918, 700 Mark V, 600 medium, 450 supply and 48 gun-carrying tanks. The Mechanical Warfare Supply Department could produce only 200 Mark V, 250 medium and 48 gun carrying tanks, while supply tanks could not be produced at all by that date. Investigation showed that much difficulty had arisen not only from lack of co-ordination between the users and producers of the new machine but also from the necessary changes arising out of the development of types. Mark IV had not proved reliable. Mark V had not yet been made and alterations in its design were still being suggested. There were differences of opinion as to the approval of Mark VI and Medium Mark A ; Mark B was suggested in place of Mark A, but there were still points in its design which remained unsettled. If agreement on these could have been reached immediately it would have been a month or six weeks before manufacture could begin. Supply tanks were asked for in July, 1917, but no agreement had been reached as to their form. All the material for Mark IV machines was too far advanced to stop the completion of the 1,400 machines ; but 200 of the surplus were to be completed as supply tanks. Designs were being completed to alter the rest so that they should take the epicyclic gear and the 150 h.p. 6-cylinder engines and also to alter the Mark IV, which would come out of commission as Mark V was delivered. There were on order 800 Mark V machines, all of which were to be delivered by the end of May. Longer tanks were needed to meet the widening of the German trenches. Experiments were being made in this direction in

order to fix the design for the remaining 800 machines, which would complete the total requirements of the War Office for 9 battalions. The change involved serious problems, since every foot of increased length involved an increase of a ton in weight and a corresponding increase in engine power. The supply tanks were needed for three separate purposes; (1) to keep fighting tanks in action; (2) to keep infantry in action and thus to save the withdrawal of fighting men as carrying parties; (3) to carry infantry protected against shrapnel with a view to creating a completely mechanical army. The gun carrying tank was suitable for all these purposes.

Track links were the limiting factor in production. The total output of links was 80,000 per month rising to 130,000 per month, all of which were required to provide and maintain the fighting tanks. Another difficulty was the supply of ball bearings. The growing demand for these was not confined to tanks, which ranked in priority after aircraft, guns and motor mechanical transport and received, in common with other stores, a percentage only of their requirements.[1]

(*d*) Centralisation of the Control over Tank Design, October, 1917.

While new problems of manufacture and design were thus continually arising, it became essential to ensure proper co-ordination between the authorities concerned. The chief difficulty arose from the diversity of the bodies concerned with design. The Mechanical Warfare Supply Department alone had direct knowledge as to tanks until they were issued. Then the officers in France acquired superior knowledge of the use and deficiencies of machines supplied while the Tank Directorate at the War Office were seeking independently to remedy trouble experienced in the training camps. Thus three different bodies were making trials and doing experimental work without any proper co-ordination. The War Office Tank Committee controlled general design and its members had originally included representatives of the supply department, but not of the Tank Corps in the field.

In order to obviate these difficulties, the responsibility of the Mechanical Warfare Supply Department for design was confirmed in October, 1917, and to make its functions more apparent its name was changed to "Mechanical Warfare Department." The designers in the department were brought under one strong head, who also presided over a committee upon which the tank users were represented. Experimental design was separated from production design and the experimental branch from the supply branch of the department. All these branches were placed directly under the head of the design branch. All requests for materials peculiar to tanks thenceforth went through the Mechanical Warfare Department to other departments of the Ministry and not from the War Office direct to those departments. All papers or complaints with reference to changes of design, etc., from France or from Wool came in duplicate direct to the War Office and the Mechanical Warfare Department. The Mechanical Warfare

[1] Vol. VIII, Part III, pp. 76 *et seq.*

Department acted as technical advisers of the Tank Department at the War Office. In order to facilitate co-operation between military, design, and supply, authorities, certain changes were made in personnel and Admiral Moore replaced Colonel Stern as Director-General of the Mechanical Warfare Department on 18 October, 1917.

About the same time, early in October, 1917, the first War Office Tank Committee was replaced by a new advisory committee consisting of the G.O.C. Tanks in England (Major-General Capper), the G.O.C. Tanks in France (General Elles), the Director-General of the Mechanical Warfare Department, and the Chief Technical Adviser of the Mechanical Warfare Department (Sir E. T. d'Eyncourt). This committee met fortnightly in France and in England in turn (*a*) to discuss the requirements and possibilities of supply and to formulate programmes; (*b*) to advise what lines experimental work should take; (*c*) to discuss tactics affecting design; (*d*) to arrange for a close liaison between the producers and the users of tanks. Any general specifications as affected by conditions at the front were to be discussed by the committee. Actual design was to be carried out entirely by the Mechanical Warfare Department.

Intimate knowledge of conditions in the field was obtained by appointing a representative of the Mechanical Warfare Department to control the repair shop, which was established in France instead of the battalion workshops, while a representative of the Tank Corps in France and a representative of the Tank Department in the War Office were made members of the design branch of the Mechanical Warfare Department and attached to its experimental section.

IV. Changes in Programme, October–December, 1917.

(*a*) Revision of the 1918 Programme.

The central workshop in France had evolved unditching beams to overcome the deficiencies of Mark IV tanks in regard to flotation and unditching, and with this additional equipment they fought in the third battle of Ypres. The tanks proved their worth in isolated instances; but they received only faint praise in the reports which reached home. The indeterminate achievements of tanks delayed further decision as to future production between July and October, 1917. The War Office submitted a definite and revised programme on 15 October. Of the tanks which had been ordered for the 1917 programme, 769 Mark IV tanks had already been delivered by the end of September. No more than 800 in all were required for France. Another 150 (making a total of 950 Mark IV tanks) were to be accepted for training in England and for small demands from other theatres of war. Of the remainder, 216 were to be accepted as tank tenders or supply tanks if suitably converted. The remaining 234 were not required at all and the contracts were to be cancelled or the machines stored by the Ministry as a reserve. The 200 Medium Mark A tanks were to be accepted for the army in France, but no more of that type were required. The 48 gun-carrying, and 2 salvage, tanks already ordered were also to be accepted.

In future, there were to be equipped and maintained with the most up-to-date type of tanks, 9 battalions of heavy and 9 battalions of medium fighting tanks at 60 per battalion. The Mark IV heavy tank was to be replaced by the Mark V. The engine power of the Mark IV had proved insufficient on bad ground. Its secondary gears made turning slow and difficult and engaged two members of the crew besides the driver. The officer had to attend to the brakes. Engines of greater horse power and epicyclic gears gave the Mark V greater speed and turning power and an observer's turret increased the field of view, but bad ventilation proved to be a great defect in this type. By 1 June, 1918, 600 Mark V machines (including 60 for training), 200 Medium A and 380 Medium B machines (including 40 Medium B for training), 216 tank tenders (1 to every 5 machines) and 12 salvage tanks for 3 salvage companies, were required. There were required by 1 May, 200 shrapnel-proof infantry supply tanks to carry 10 tons or 30 infantry men each. The Mark V tanks were to be in equal proportion of male to female. The medium tanks were to be of machine gun type only with a 3-pdr. anti-tank gun. Replacements of Mark V and Mark B at 108 per month, of infantry supply tanks at 20 per month and of salvage tanks at 1 per month, were to be provided from June to November, 1918. No replacements of tank tenders were demanded pending the evolution of a design for that special purpose. Not more than 800 Mark V and 650 Mark B were to be produced. If no improved type could be produced after these totals were reached, replacements of Mark V were to be provided by converting Mark IV machines. A liberal proportion of spare parts was to be supplied concurrently with the tanks of various kinds. It was arranged to order immediately 650 Mark B tanks from a limited number of firms, so as to overcome the difficulty previously experienced in obtaining continuity of output when contracts for small numbers only could be placed. Provision was made for supplying 150 gun-carrying tanks, of which 40 were to be for gun carrying, 10 for salvage, and the chassis of 100 others for infantry supply tanks. Upon taking control of the Mechanical Warfare Department, Admiral Moore anticipated that the 950 Mark IV tanks would be completed and 216 converted into tank tenders by January; that 175 Mark B tanks would be completed by 1 June and 100 each succeeding month; and that he could meet the War Office demands in respect of the other tanks. Events proved that this assurance was based on insufficient consideration of the supply difficulties involved.

Enthusiasm for the new weapon of war was revived by the battle of Cambrai, which ended tank operations for 1917. The central workshop again provided equipment necessary to success by evolving and making a bridging device in the form of huge fascines. The tanks were employed in considerable numbers (9 battalions with 42 Mark IV tanks each) and without artillery preparation. The cost of shell fired in the third battle of Ypres between 31 July and 18 November was £84,000,000 and the area captured was 54 square miles. The corresponding figures for the battle of Cambrai which was fought between the 18 and 25 November were £6,600,000 and 42 square miles. Sir E. Tennyson d'Eyncourt took advantage of the success which

had attended this first employment of tanks in the manner for which experts had always pleaded, to press for an increased use of the new arm, suggesting that three tank armies should be formed, each with 500 tanks as their primary weapon and with infantry and artillery (100,000 men) as auxiliary arms.

(b) JOINT SUPPLY WITH AMERICA.

While the development of British tanks was still in the balance, the Government of the United States was endeavouring to hasten American production. In April, 1917, information as to designs had been requested in order to facilitate manufacture of machines then in hand in America. British supply authorities were the more anxious to encourage American production, in that the request for home supply then bade fair to be small. In June, 1917, an Inter-Allied Tank Bureau was established. When Colonel Stern was released from the control of the Mechanical Warfare Department, he was appointed British Commissioner to secure the co-operation of the United States and British Governments with a view to increasing the output of tanks in 1918. The Mechanical Warfare (Overseas and Allies) Department was set up on 1 November, 1917, to put into effect a partnership between the United States and the British Governments for the production of at least 1,500 tanks of the Liberty type. These machines were to be erected in France. The first 600 were to be supplied to the American forces. Great Britain undertook to supply armour, armament, ammunition and unskilled labour. The employment of Chinese labour was contemplated. The United States Government undertook to supply engines, transmissions, forgings, chains, etc., and some skilled labour. A factory was to be erected and equipped at Chateauroux at a cost of £250,000. It was to produce 300 tanks per month and to be capable of being extended to produce 1,200 tanks per month. It was to be under the joint control of an American Commissioner and a British Commissioner, with a staff to organise production in England and with English facilities for drawings. It was anticipated that deliveries of the 1,500 tanks would begin in March or April, 1918, and be completed by October. The American Government undertook to replace with ship plate, on a basis of ton per ton, the steel provided by the British Government for armour plate.

Representatives of the American Tank Corps attended meetings of the War Office Tank Committee which determined the general specifications of the Liberty or " Allied " (Mark VIII) tank. It was to have 300 h.p., 14 feet crossing power and 30 tons weight against the 100 h.p. 11 feet and 25 tons of the Mark IV. Details of design were entrusted to a committee consisting of the British and American Commissioners (Colonel Stern and Major Drain), representatives of the respective Tank Corps (Captain Greer and Major Alden) and Sir E. Tennyson d'Eyncourt. Any alteration affecting general design was to be approved by the Tank Committee. The Controller of the Mechanical Warfare Department was responsible for the delivery of all material other than armament and equipment. The necessary priority was to be given by the respective Governments.

The War Office on 13 December, 1917, gave provisional temporary priority to tank requirements. The supply of material for, and manufacture of tanks under, the joint scheme were not to interfere with the War Office programme for 1918 extended by a further 300 Mark V tanks. It was not found feasible to furnish by the time specified the armament required for the joint scheme in addition to that required for the War Office programme. Moreover, the War Office itself contemplated a considerable increase in its tank programme after the battle of Cambrai. The Minister (Mr. Churchill) anticipated a possible yearly production of 10,000 tanks of which 4,500 would be produced in England and the balance in France. The Mechanical Warfare Department estimated that output might be increased to 3,260 Mark V or similar tanks and 650 medium tanks, exclusive of the materials to be provided for the Allied programme. A further use of locomotive works was also suggested. The requirements for materials were extremely heavy, as is shown by the following table :—

MATERIAL REQUIREMENTS PER 100 TANKS.

	For Heavy Tanks.	*For Medium Tanks.*
Armour Plate	1,100 tons	550 tons
Steel	1,930 ,,	1,161 ,,
Steel Alloy	100 ,,	75 ,,
Cast Iron	170 ,,	50 ,,
Copper	22 ,,	13 ,,
Yellow Metal	38 ,,	25 ,,
Aluminium	5 ,,	4 ,,

The requirements of material for the inter-allied programme of 1,500 machines included 18,000 tons of armour plate, and 12,900 tons of mild steel.

The limiting factor in production was the supply of links and of armament. It had been realised in the autumn of 1917 that it was essential to supplement the output of cast steel links to fulfil the tank programme. A drop forged link had been designed, but very serious difficulty was encountered during the process of stamping, through lack of experience among contractors in working on the forged type of link. The extended programme required special facilities in the way of steel supplies, the allocation of further stamps and machine tools both in connection with die-sinking and machinery. A central link-machining workshop was proposed where an installation specially devised for the work could be run on repetition lines. The position in regard to the armament required for the tank programme of the War Office and that of the joint scheme was considered on 29 December, 1917. There was then capacity for 320 6-pdr. guns per month, but the need for making 2-pdr. guns for Whippet tanks reduced this figure to 200 per month. This left no surplus for the inter-allied programme. The 2-pdr. guns could not be produced within four months of the receipt of drawings. The drawings were not then approved. Probable demands were in excess of existing capacity. The Minister's proposal to produce 10,000 tanks per annum involved 1,400 6-pdrs. and 5,000 machine guns per month, while the maximum capacity of existing plant was 320 6-pdrs. and 1,600 machine guns per month. It was necessary to arrange for largely increased capacity. It was decided, therefore, to change back the 2-pdr. plant to 6-pdr. manufacture and to get an output of 2-pdrs. as quickly as possible.

CHAPTER V.

EFFORTS TO EXPAND PRODUCTION, 1918.[1]

I. Increased Demands and Reduced Production.

(a) The Extended War Office Programme.

While the battle of Cambrai had established for good the value of tanks as a weapon of war, the method and amount of their employment still remained a matter of uncertainty in the eyes of the military authorities. Nevertheless, the use of tanks in largely increased numbers became the governing principle of supply, and Mr. Churchill's maximum programme remained in advance of the army's formal demands. Its immediate realisation was, however, precluded by several circumstances, particularly by delays in the construction of the factory at Chateauroux, and by lack of steel for the increased armament which it would require. Moreover the development of mechanical warfare on so large a scale was still hampered by difficulty in providing the necessary *personnel*.

The agreement between the United States and the British Government was signed on 22 January, 1918. The Mark VIII tank, which was to be produced under this agreement, was also adopted by the War Office as one of the standard British types. Arrangements had been made at the end of 1917 with a single firm to produce all the jigs when drawings became available, so that the American Government might undertake simultaneously the production of a similar type in America. Additional sets of jigs were ordered so that the parts of all these machines might be interchangeable. It was, however, found in March, 1918, that the limits specified on the jig drawings were incorrect and work was suspended while other drawings were produced.

The beginning of the new year was marked by a decision to reorganise the Tank Corps and as a result of experience gained in recent fighting, the War Office put forward a new and increased programme for 1918. Instead of 9 heavy and 9 light battalions each with 60 tanks, there were to be 12 heavy tank battalions, each with 48 machines and 6 light battalions, each with 65 medium tanks. Three battalions constituted a brigade and two brigades formed a group. Besides these fighting units there were to be 6 tank supply companies, each with 24 tanks, 2 wireless sections (4 tanks each), 3 cable laying sections (2 tanks each), 2 gun carrier companies (24 tanks each) and 3 tank field companies (3 tanks each). Additional tanks were also demanded to equip two brigades of heavy, and one of medium, tanks. Replacements were asked at the rate of 20 per cent. per month for fighting tanks and

[1] Based mainly upon Mr. Churchill's papers, memoranda for 1918, *penes* Sir Albert Stern, papers relating to programme (D.M.R.S.341 H. and Hist. Rec./R/1940/7), and the same sources as Chapter IV.

10 per cent. per month for the other kinds. The total requirements under this programme for 1918 were 1,654 heavy tanks, which were to be Mark V, altered as soon as possible to a longer type with a more powerful engine ; 1,028 medium tanks, of which a faster type of no greater weight was to be introduced as soon as possible ; 325 tank tenders, 216 of which were to be converted Mark IV, to be replaced later by tanks of the gun carrier type ; 18 " wireless " tanks, which were to be converted Mark IV to be replaced later by the gun carrier type ; 9 cable laying tanks of infantry carrier type ; 312 infantry carriers. A proposal to supply 50 gun-carrying tanks and 17 salvage tanks was cancelled in March, 1918, when it was arranged that existing gun carriers should be equipped with cranes in France and used for salvage purposes. The War Office asked that new types of tanks should be ordered in blocks of the smallest quantities consistent with rapidity of output.

(*b*) Decreased Output.

The prospects of meeting this extended programme were prejudiced by a steady fall in output since the re-organisation of the Mechanical Warfare Department in October, 1917. The diminution in output was due to various causes, including the depletion of headquarters staff which accompanied the re-organisation. The small number of tanks requisitioned and the time allowed to elapse before new demands came forward also hindered the development of supply. Thus, the decision to proceed with the manufacture of Mark V was delayed from June till October, 1917, so that the machine was only just past its running trials in January and the makers reported that output could not begin until the end of the month. Subsequent strikes caused further delays. Again, the work of the design branch became considerably congested. The detailed drawings for the conversion of Mark IV engaged the entire staff of the branch and delayed the " Medium B." Design work for the Overseas and Allies Department then absorbed almost the whole London office of the Mechanical Warfare Department. The design work for Marks V, V* and Medium B had to be done at the works of the Metropolitan Carriage Wagon and Finance Company. The design branch again became responsible for the production of engines and transmissions, and the production of armour plate was assigned to an officer who was responsible also for priority, labour and machine tool releases. This centralisation of the duties of the department in the design branch proved injurious to output.

Orders were cancelled in respect of 180 Mark IV machines and thus a gap was created at the end of the period fixed for delivery of this type. Delivery of the Medium Mark A machines had already begun in October, 1917, but deliveries were slower than had been anticipated owing to difficulties in obtaining supplies of ball bearings for the rollers. This machine had been designed to take an " out " size which was believed to be in stock in the country, but in the event the supply was only obtained with the utmost difficulty. Manufacturers were not adhering to the schedule of deliveries for gear boxes and epicyclic

gears. The facilities available were not adequate to meet the requirements of the department. The department had no outside production officers, and its inspection staff was inadequate for the dual responsibility for progress and inspection. The provision of the necessary armament was also a matter of difficulty and was considered on 23 January, 1918. Some relief was then anticipated on this score through delay in the output of tanks from Chateauroux. This output was originally expected to begin in February, 1918, but production was postponed from time to time. The problem of armament supply was nevertheless so grave, that the Ministry was eventually obliged to propose a modification in the War Office tank programme for 1918. Revised estimates of output were put forward on 20 January, 1918. It appeared at a conference on 10 February that the output of Mark V which began in that month, would be 139 short of the estimate by the end of March. The Minister himself intervened with the manufacturers who, thereupon, undertook to produce 660 Mark V and Mark V* tanks by the end of June.

The scheme for the general allocation of steel was applied to tank production in February, 1918. Thenceforward, contractors had to schedule their requirements in advance and to purchase their supplies from allocated sources. Supplies of material were not, however, balanced by machining facilities and the output of armour plate suffered in consequence. Mr. Perry, who was appointed Deputy Controller in 1918, reported that the difficulties in regard to steel castings were being overcome and that gear boxes would be produced at the rate of 45 per week, commencing in 3 weeks time and working up to 65 per week. The shortage of material had an adverse effect on the supply of labour for tank erection. In one instance it was reported that a firm had capacity for erecting 40 machines if labour were available. Extraordinary and personal efforts were made by the Minister to remedy this position. Labour was transferred to tank manufacture. The shortage of machining facilities was not, however, recognised at this time as the root cause of the evil.

II. New methods of Production.

(a) Departmental Changes.

In February, 1918, the War Office put forward their minimum requirements until 1 August, including additional tanks for counter-attacks and in case of wastage in fighting. At the same time it was evident that prospective supply was far below the needs of the Allied armies. Actual output continually fell below estimates, and a general reorganisation was undertaken as a means of remedying the position. The first step taken was the internal reorganisation of the Mechanical Warfare Department along more efficient lines. The supply section was divided into six sub-sections, which were again sub-divided into groups, each group being placed under an officer who was responsible for a particular type of work. The outside staff of the newly established Engineering Department of the Ministry became available

as local progress officers. A proposal for the formation of a Tank Board to consist of officers concerned with design, construction, supply and experiment as well as military representatives, was put forward by Sir Arthur Duckham, but remained for a time in abeyance. Mr. Churchill, however, appointed a Committee of the Munitions Council with instructions to accelerate deliveries of tanks and to consider the tank programme for 1919. There was also a strong body of opinion in favour of concentrating the control of training and tactics under the supply authority.

(b) Expansion in the Sources of Supply.

There were under manufacture at this time, 192 Mark IV and Mark A machines, which were the residue from the 1917 programme and were on order from five firms, including the two original manufacturers of Mark I. In addition, contracts had been placed for the 1918 programme for a total of 1920 machines including Marks V, VII and B, supply tanks, gun carriers and salvage tanks. The production of the two latter classes was abandoned in March, 1918. Orders for the remaining machines were distributed among six firms, by far the greater number (1,400 of Mark V or its modifications and 450 of Mark B) being placed with one of the original tank-makers, the Metropolitan Carriage Wagon and Finance Company.

Engine construction was reported to be well in hand to meet existing demands ; but ere long it proved to be a limiting factor in the output of complete tanks. It had been decided in August, 1917, to build 4-cylinder units giving 100 h.p. of the same type as the 6-cylinder 150 h.p. ; and also to design a 225 h.p. type of 6 cylinders. The drawings of the 225 h.p. engine were completed in September, 1917, but, owing to delays in settling programmes and in placing contracts, work did not begin until January, 1918, and this type for use with the Mark V* * did not come into service before the Armistice. An order for 300 of the 100 h.p. engines, subsequently increased to 466, was placed with a single firm of engineers and additional orders for 100 each were placed with two other firms. Trials of the first engine of this type were not, however, run until February, 1918. It had been decided in September, 1917, to build a 12-cylinder 300 h.p. engine. The manufacture of this type involved the occupation of a considerable floor space for a slow output. It also presented many technical difficulties. A year elapsed before the first engine was running ; but the effort to put this type into production considerably disorganised the whole output of engines. Only six of this type were produced up to the Armistice.

The nature of the military operations in France was effecting economies in shell steel to the extent of 10,000 tons per week, and the Minister accordingly resolved to press forward his maximum programme for tanks at any rate so far as output from England was concerned. He urged the Council Committee to increase the output of tanks to a total of 100 per week. The Metropolitan Wagon and Finance Company had so far maintained a virtual monopoly in tank erection.

In order to spread the sources of supply, it was now arranged to utilize for tanks unemployed capacity at the works of two locomotive makers. A conference was also called with a group of manufacturers from South Lancashire nominated by the Director of Area Organisation. The group was under the Chairmanship of Mr. West of the West Gas Improvement Company, Ltd., Manchester, and was expected to produce 300 h.p. engines for the Mark VIII machine at the rate of 320 per month, in addition to the hulls required for the Overseas and Allies Department. With these and other new sources of supply, the Controller of the Mechanical Warfare Department anticipated that he could secure an output of 400 tanks per month from October, 1918, onwards, provided that his responsibility for production under the inter-allied programme was restricted to the original 1,500 tanks. A revised programme for the erection of 4,559 tanks between February, 1918, and March, 1919, was considered by a conference at the Ministry of Munitions on 7 March, 1918.

At this time, it was reported that two or three weeks elapsed before tanks which arrived in France were fit for the fighting line, owing to rectifications found necessary in consequence of faulty inspection at home. This gave rise to 10 per cent. of the labour in the army workshops. A committee was appointed to make definite proposals for the establishment of an experimental workshop, which had not yet been carried out, and it was hoped to meet the difficulty reported by establishing a general testing ground in connection with this experimental workshop. Complaint was also made that delays were caused by frequent alterations in design during manufacture, and it was agreed to determine a system of alteration dates, seeing that it took nine months before radical alterations in designs could come into production. The Mark VIII and Medium C were definitely approved for the 1919 programme and the Tank Committee was instructed to draw up as soon as possible their specifications for a new machine of tank destroyer type.

Some objections were raised to the increased programme on the score of its effect on the shipbuilding programme since it required 193,000 tons of steel (including provision for the inter-allied production), while the supply of steel allotted to tanks by the Steel Allocation Committee was only 46,000 tons per annum. The revised programme was, however, sanctioned subject to the proviso that if it entailed a shortage of steel, no reduction was to be made in the amount approved for Admiralty purposes. The provision of 10,000 6-pdr. guns and 30,000 machine guns was also approved, and the Minister gave instructions that the extensions required to provide this armament should be treated as most urgent. It was decided to abandon production of the 2-pdr. gun in order to secure adequate output of 6-pdrs. In the event of difficulty in manning the new tanks, it was anticipated that *personnel* might be provided by the Allies.

(c) TEMPORARY IMPROVEMENT IN OUTPUT.

Production improved so considerably under the supervision of the Council Committee that during March the rate of output gave promise of exceeding the rate of training. The American Government asked

that tank wagons for transport of fighting tanks should be manufactured in England, and this was agreed to, on the understanding that if the steel required were not provided by the United States it would be deducted from the inter-allied programme. The Cardonald National Projectile Factory was added to the list of tank manufacturers with an estimated capacity for producing 10 tanks per week, rising to 20 per week, but its conversion to this work did not materialize before the cessation of hostilities. Mark V machines began to arrive in France when the German advance began, by which time also a battalion was equipped with Medium A tanks (Whippets). The number of tanks lost in the advance brought up the total wastage to 257 by the middle of April. There were then available in England and France 902 machines. The state of production, however, was regarded as good enough to allow of a modification of the existing first class priority, in the case of non-limiting factors, so as to improve the position in regard to other war material. At the end of April it was agreed, in view of the good supply of tanks and difficulty experienced in training *personnel*, that a number of Mark V tanks should be offered to the French in exchange for Renault light tanks and in order to allay disappointment caused to the French by delay at Chateauroux. All through May, Mark V tanks were arriving in France at the rate of 60 per week. By the middle of the month the 200 medium A tanks and all but 33 male and 8 female of the 400 Mark V tanks were completed. The War Office then decided to retain the whole issue of Mark V tanks in order to replace immediately the Mark IV, which it was proposed to store at Chateauroux, and to offer the French 100 Mark V*. By the beginning of June, the tank tenders which had been ordered were completed and the Mark V* and the infantry supply tanks were beginning to come through.

The superior manœuvring power of the Mark V over the Mark IV was confirmed in an action fought at Hamel early in July by 60 tanks in co-operation with Australians. Only three tanks were damaged and these were salved. There were about 400 Marks V and V* in France when the attention of the Mechanical Warfare Department was called to complaints that the increased life due to the introduction of manganese bronze sprocket wheels was practically negatived by unreliable mobility resulting from the weakness of the hub, which was due to faulty design or faulty execution of design. It was found that the bearings of the gear boxes had been miscalculated in the original design. In order to avert delay in output, supplies of a new bearing were manufactured and inserted in the gear boxes after completion. By the middle of July the army had received 397 Mark V and 120 Mark V* machines.

The losses suffered in the German advance had resulted in a call for an accelerated output of Mark V. All firms working on gear boxes and epicyclics were consequently ordered to produce these components for the Mark V and the Mark V* type to the ultimate detriment of the Medium C and the Mark V**. Deliveries of Mark V** were expected to begin in December at the rate of 150 per month. The War Office, however, asked that 400 Medium C tanks should be ready by 1 April, 1919. The department placed orders for 200 with the

South Lancashire Group. A similar combination was called into being by the department in the Leeds district under the leadership of Messrs. Kitson and the other 200 Medium C tanks were ordered with manufacturers in that district.

At the end of May, 1918, the military representatives of the Supreme War Council called for the production of 3,800 heavy, 820 medium, and 8,500 light, tanks for the 1919 tank programme. They proposed that the tanks of any Ally should co-operate with the infantry of any other and that an inter-allied training centre should be established. A request from Monsieur Loucheur, the French Minister, for 9,150 tons of steel per month towards the French manufacture of 1,200 tanks monthly was under consideration in July. The American Government also asked for material for additional allied tanks over and above the original 1,500. The War Office increased its demands to 6,940 tanks of which there were to be 900 Mark V**, 2,400 Mark VIII (including 1,500 from Chateauroux), 1,750 Medium C or D and 1,400 infantry carriers by 1 June, 1919. The War Office demand alone required an additional 37,000 tons of steel. Output from Chateauroux was not expected to begin before March, 1919. The whole question of supply to Allies was referred to the Tanks Committee of the Inter-Allied Munitions Council in order that a co-ordinated programme for tanks might be settled for all the Allies.

III. Difficulties and Delays.

The improvement in output during the early part of 1918 was largely due to the special effort made by the Metropolitan Wagon & Finance Company in response to the Minister's appeal. This Company protested against the increasing employment of new firms, on the ground that more labour was needed and instruction had to be sought from themselves. They contended that with their accumulated experience in tank manufacture, their own capacity could cope with greater output if material and labour were provided. The improved output was, indeed, only a temporary amelioration of a condition which needed a more drastic remedy. Deliveries had once more begun to fall short of estimates in May. By the end of July the estimates which had been submitted in March were being realised to the extent of 33 per cent. only, and even revised estimates of the 6 July were being realised to the extent of 50 per cent. only. It was anticipated that there would be a deficit of 3,048 tanks on the latest War Office programme up to June, 1919.

One of the causes which contributed to this result was delay in securing fixed working drawings. In some cases the firms were responsible for designs, in others the Mechanical Warfare Department, and in one case a committee of designers. While discussions as to improvements and alterations continued between designers and users, the interests of output fell into the background. Standard designs were not available, preliminary drawings were delayed and did not always reach the necessary standard of accuracy. Between February and July, 1918, nearly 2,000 alterations to working drawings were

sent to contractors. Estimates of production had not been based upon reliable data in regard to the condition of components supply. Considerable difficulty was experienced in applying to tank contractors the procedure which the Ministry had established for controlling the supplies of stampings and castings. Tanks required 25 per cent. of the total output of steel castings. The gear blanks required wire of large size and of high tensile alloy steel. The drop stampers allocated by the Controller of Forgings and Castings refused to accept this class of work. The engine and gear box manufacturers refused to accept the allocations made. The situation did not materially improve until close control was modified in September. The situation in regard to ball bearings was difficult also, and only one firm was available for the roller bearings. The withdrawal of men for the army in consequence of the "Clean Cut" regulations, and the epidemic of influenza which raged in the Midland and Eastern Counties, also affected output of tanks so that instead of 260 Mark V* only 112 were produced in June, 1918.

The situation in regard to armour plate was still very grave, owing to the production of raw material in excess of machining capacity. The limiting factor was the capacity for heat treatment, which was carried out by contractors under the Mechanical Warfare Department. The supply of armour plate had, indeed, only sufficed so far because output of tanks had fallen short of estimates. Output of engines had fallen to 184 per month, having been disorganised by the attempt to get a 300 h.p. engine into production. The attempt had been pressed forward owing to the failure in the expected supply of "Liberty" engines, of American manufacture. The 100 h.p. engine which was intended for the Medium B and the 225 h.p. engine which was intended for the Mark V** entered the production stage about July, 1918. The 150 h.p. engine had been used in the 400 Mark V and in some Mark IV tanks. It was being used in the Mark V*, the Mark VII (hydraulic gear type), the Mark IX (infantry supply) and the Medium C tanks. The supply of engines came from eleven firms most of whom were old established engine builders. Their total capacity could not produce more than 500 per month and that only if working on well-known types and with adequate material in sight.

IV. Creation of a Tank Board.

To meet the position, the French Government was asked to accept surplus Mark IV machines produced by the department in excess of the formal demand. Arrangements were also made to despatch Mark V* machines to the British, French and American armies in turn. At the end of July an effort was made to obtain more reliable estimates than those which had been based on previous returns from the manufacturers. The Minister called a meeting of the principal tank erectors, as a result of which revised estimates were obtained. These provided for the delivery by 1 July, 1919, of 5,629 fighting tanks, of which 4,500 should be in France by 2 June, 1919, besides an expected output of 750 from Chateauroux.

On 7 August, 1918, Admiral Moore was succeeded as Controller of the Mechanical Warfare Department by Mr. J. B. Maclean, who had previously been in control of gun manufacture and later of the Engineering Department of the Ministry. About the same time, the production of light gun tractors with caterpillar tracks was undertaken to meet an emergency demand, and the Deputy Controller (Sir Percival Perry) devoted the whole of his attention to this particular work.

Mr. Maclean submitted greatly reduced estimates of deliveries based on the condition of production at the time. It was apparent that the fall in the output of components with the accompanying loss of labour might have resulted in a total cessation of deliveries by the end of the year if the policy of the department had not been changed. Mr. Maclean hurried on extensions to the plant of four of the largest and best engine builders, ordered large quantities of new plant for transmission gears, provided new machinery for the production of armour plate and simplified the procedure with the Ministry's control departments, all to secure his reduced estimates of deliveries. Responsibility for various classes of production was centralised in the supply section, and its status was raised under an Assistant Controller (Captain A. E. Gelder). A tentative scheme had been placed before contractors by the Minister under which production generally would have been governed by a committee of manufacturers. The new Controller's grasp of the realities of production made this scheme superfluous and it was never put into effect.

Concurrently with the changes within the Mechanical Warfare Department there were also effected changes in the supervisory organisation under which the department worked. Efforts had been renewed in May to assimilate the control of the Tank Corps with the general military organisation. The growing importance of tanks made it peculiarly desirable that they should be treated as an integral part of the army. It had been considered necessary at first to keep the development of the new arm distinct within the War Office. It was, however, contended that this separate organisation was cramping the development of mechanical warfare and that since tanks had been accepted as a definite part of the general scheme of warfare, their organisation should be assimilated to that of other arms. This proposal involved the breaking up of the Tank Directorate under General Capper and the distribution of some of its staff over other departments, as well as the reorganisation of the Mechanical Warfare Department. In July, 1918, the War Office put forward proposals for the reconstitution of the Tank Committee on the abolition of the Tank Directorate. After some discussion as to the desirability of maintaining the comparative independence of the Tank Corps, it was agreed to concentrate responsibility in a single committee which was established as the Tank Board and held its first meeting on 15 August, 1918. The Deputy Minister of Munitions (Major-General Seely) became President, Sir E. Tennyson d'Eyncourt was appointed Vice President with special duties in regard to design. Research was further represented by the Controller of the Munitions Inventions Department. The Army Council was represented

by the Master General of Ordnance; conditions in the field by a member of the General Staff, War Office, and by G.O.C. Tank Corps, France. Supply was represented by the Controller of the Mechanical Warfare Department, the newly appointed Director of Traction (Sir Percival Perry), and by the Commissioner of Mechanical Warfare (Overseas and Allies), Sir Albert Stern. The Board became responsible for formulating production programmes and general specifications in accordance with the army's requirements. It controlled research work, was responsible for inspection and advised the Minister generally on questions relating to tanks.

V. The Final Programme.

While these changes in organisation were in progress at home the Tank Corps was heavily engaged in France. Twenty German divisions were defeated by thirteen British infantry divisions and three cavalry divisions supported by 400 tanks. The Tank Corps reserves were used up. The tanks and their crews were almost fought to a standstill by 11 August, 1918. It was anticipated that the Mark IV tanks would have to be recalled into action and the previous decision to hand these over to the Allies was accordingly cancelled. The number of tank brigades had been reduced from six to four in May, in consequence of heavy losses suffered by all arms during the German advance. Demands were made for greatly increased production, but, as narrated above, they were met by a falling output. In August, 1918, an augmented tank programme was considered to be at the moment the most vital requirement of the allied armies in France as a means of reaching decisive results, and on the ground that the ratio of the results obtained to the material and man-power used was greater than in any other arm. The first class priority in favour of tanks was renewed. Special arrangements were made for securing the necessary headquarter staff and modifying the stringency of control over stampings and castings in order to meet the requirements of the situation.

A meeting of engineering firms was convened in Leeds on 23 August, 1918, under the chairmanship of Captain Gelder, and a scheme was formulated for a Yorkshire tank erection group which became the North of England group. It was self-contained, being able to produce all the components for erecting 100 tanks per month, excepting equipment. A production committee of leading manufacturers in the South of Scotland was formed under the chairmanship of the Director General of Munitions in Scotland to work under the department, as did the groups formed in Manchester and Leeds. The first task of this committee was to consider production of Mark VIII tanks which were ordered from a firm of locomotive makers when the first machine was ready for testing. The trial runs revealed inherent defects due to faulty design, and it was decided that production work on this type should cease. Instead, 2,630 Medium C machines were ordered for immediate manufacture by the Scottish firms concerned. The change over in the supply of components involved new contracts which, during six weeks, amounted to £14,000,000.

Deliveries of Medium B tanks began on 9 September, 1918. The War Office on 17 September formulated their requirements for 1919 to meet the decision for the extension of the Tank Corps. They demanded 3,600 fighting machines (including 100 per cent. reserve in this total). Of these, 1,200 or 1,800 were to be Mark V or V**. The rest were to be Medium B or C. It was asked that 66 per cent. should be in France by 15 March, and 34 per cent. by 15 June, 1919.

The production of driving chains in Great Britain was at this time proving inadequate to meet the increasing demands arising from tank production. A co-operative committee was formed, as a result of a conference of manufacturers held at the Mechanical Warfare Department, so that new and inexperienced manufacturers received the advice of Messrs. the Coventry Chain Co. and Hans Renold, Ltd., who had previously been the sole British makers of large driving chains.

By October, 1918, the Scottish Production Committee was fully organised and the production of the new Medium B and Medium C tanks began. Efforts were made to advance the output of Mark VIII hulls for the Overseas and Allies Department, and a bonus scheme, based on increased production, was approved by the Minister and put into operation. The difficulties of contractors with regard to labour, however, culminated in a total shortage of 3,800 men, and on 5 November the decision was taken to procure the release of this number from the army for tank erection.

The position with regard to machines in England and France on 15 October had been reported as follows :—

Class of Machine.	*Numbers in France.*		*Numbers in England.*	*Total.*
	Fit.	Unfit.		
Fighting Machines—				
Mark IV	33	230	145	408
Mark V	125	263	—	388
Mark V*	140	78	70	288
Medium A	59	108	—	167
Total Fighting Machines ..	357	679	215	1,251
Supply Machines—				
Mark IV Tenders ..	95	103	51	249
Grand Total ..	452	782	266	1,500

The wastage of tanks had been five times as great as was anticipated, so that the stocks of spares were dangerously depleted. The Tank Corps laid it down that if continuous fighting were to take place, 100 per cent. of the machines on the establishment would have to be held in reserve on the date when operations were to begin. The close of hostilities, however, set an end to the greatly increased intensive production already projected. The general re-organisation of supply methods, under Mr. Maclean, including the co-operative schemes of production, together with the established position which tanks had won as a recognised and essential arm and the consequent facilities granted

to their production by supply and military authorities, had solved the problems which had previously hampered output. The increased demands which the Tank Corps submitted required an addition of over 2,000 machines to the estimated output till March, 1919, and the Mechanical Warfare Department was prepared to undertake this new task when the Armistice called a halt to its operations.

The scheme for joint production had not materialised when hostilities ceased. The Commissioners under the Anglo-American agreement had handed over responsibility for the construction of the factory at Chateauroux to the Ministry of Munitions early in the year and the work had been assigned to the Department of Factory Construction under Sir John Hunter. The whole position was investigated in August, 1918, upon a proposal that the French Government should undertake the erection of the factory. It was, however, arranged that the Commissioners, the Department of Factory Construction and the contractors should all be represented on the spot, but no one of these had supreme responsibility and 1,300 men were employed to little purpose. Improvement was ultimately achieved by the appointment of Messrs. S. Pearson & Son as Construction Managers with Mr. Hopkinson, their representative, in control, and an appeal was made to the Commander-in-Chief for the loan of 1,000 prisoners of war to hasten the work. A board of experts was sent out in October to examine and report on the contemplated arrangements for dealing with the assembly of tanks at the factory.

In addition to these final efforts to supply increased numbers of tanks, considerable attention was paid to preparations for the production of light gun tractors on caterpillar tracks, undertaken by Sir Percival Perry in August, 1918. The evolution of this machine had an important bearing upon the problem of mechanical transport and is considered elsewhere.[1] The new tractor was intended to replace the supply tank by a machine more readily produced. It was designed to take standard commercial engines and an adaptation of a conveyor chain which was in commercial use and needed no machining, It was thus hoped to obviate the two main problems of tank manufacture. By 1 April, 1919, 10,000 were to be ready for delivery to the army. The necessary power units and transmissions and other supplies not procurable in Great Britain were to be purchased in the United States, but hulls and all other supplies were to be purchased in England. Major Holden was transferred from the Overseas and Allies Department to take charge of the American office organisation for the new branch, but he did not arrive in America until the end of October. Sir Percival Perry left for the United States on 31 August, 1918, and part of the work undertaken in his American offices was the development of an experimental fighting tank designed to use the 110 h.p. Hall Scott engine as a power unit. Contracts for the tractor programme had been placed, production had begun and scheduled deliveries gave promise of being realised at the time of the Armistice.

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[1] Vol XII, Part IV.

CHAPTER VI.

REVIEW.

I. The Introduction of the Tank.

A peculiar interest attaches to the development of an entirely new arm and the equipment of the British forces with a novel weapon of war ultimately adopted both by the Allies and by the enemy. The first tank owed its birth to the advocacy of a few individuals who were firmly convinced that mechanical contrivances alone would serve to break through the highly entrenched position of the Germans on the Western front or to provide an adequate defence against the enemy's novel tactics of intense machine gun fire. "Mother Tank," the first of her race, was evolved under the ægis of the Admiralty, and was regarded primarily as a "land-ship." The cost of her production was borne by the naval vote. This exceptional treatment of a land service weapon was due partly to the personal interest taken by the First Lord (Mr. Winston Churchill) in the project, partly to the peculiar facilities offered by the Directorate of Naval Construction for producing so complex a design, partly to the interest of the R.N.A.S. in the development of a cross-country armoured car and very largely to the hesitation of military authorities to adopt so novel a contrivance. The proposals which were laid almost simultaneously before the Admiralty and the War Office in January, 1915, were abandoned by the latter upon the results of one or two trials and mainly by reason of difficulty anticipated in finding anyone competent to design a "land-cruiser" which should fulfil the necessary conditions.

The Admiralty Landships Committee was appointed in February, 1915, under the chairmanship of Mr. (later Sir Eustace) d'Eyncourt, the Director of Naval Construction. Military interest in the development of a landship or machine-gun destroyer was quickened by Lieut.-Colonel (afterwards Major-General) E. D. Swinton, while he was acting as official "Eye-Witness" in France and later as assistant secretary to the War Committee. In June, 1915, the Commander-in-Chief made formal inquiries as to the practicability of introducing a "land-ship," basing the general characteristics of the required machine upon Colonel Swinton's memoranda. Thenceforward, the Admiralty Landships Committee worked in direct concert with the military authorities and thus obtained authentic information as to the conditions under which the machine would be used. In February, 1916, it demonstrated before the military authorities the practical utility of a sample machine, the "Centipede" or "Mother Tank." This novel engine of war had attained its concrete, practical shape in the workshops of W. Foster and Company at Lincoln, where the details of its design were evolved by Mr. (afterwards Sir William) Tritton and Lieutenant (later Major) W. G. Wilson. It is noteworthy that the procedure which met with eventual success had been recommended by one of the original

projectors of the scheme, Captain T. G. Tulloch. In January, 1915, he had proposed that a committee should be formed of experts representing the several sciences involved in so complex a design and that the pattern should be evolved by a practical engineer and designer in the drawing office of a factory where the machine might eventually be made.[1]

As a result of the initial demonstration of the "Centipede," the Army Council invited the Minister of Munitions to provide 100 similar machines.

II. Later Developments in Design.[2]

"Mother Tank"(Mark I) was produced by Messrs. Foster and Company, Ltd., for the trials of February, 1916. Its transmission gear was that of the Foster-Daimler tractors with a six-cylinder Daimler engine of 105 h.p. It was provided with a hydraulic stabiliser in the form of a two-wheeled tail whereby it could descend a drop of 5 ft. and by the aid of which the machine was steered. Its steering arrangement was laborious. Four men were required to drive the machine and no silencer was provided. Mark II and Mark III were practically the same as Mark I, but with minor modifications. Work upon these two designs began in February, 1916, and the first of each type was produced in January, 1917 ; Mark II by Messrs. Foster and Company, Ltd., and Mark III by the Metropolitan Carriage Wagon and Finance Company. The total weight of the male tank was 28 tons and that of the female tank was 27 tons.

The Mark IV tank was also an adaptation of Mark I, but it was provided with armour of a special steel which proved impervious to the German armour-piercing bullet, and the design and material for its track rollers were improved. Danger from fire was also reduced by placing the petrol tank outside and at the back of the machine. The sponsons were so constructed that they could be pushed in for transport by rail, whereas in the earlier types they had to be unshipped. Alterations in the mounting were made to meet the substitution of the Lewis gun for the Hotchkiss machine gun, and the introduction of a short 6-pdr. gun in the male tank helped to reduce the total weight. A silencer was fitted and the driver's turret was reduced in width to allow the use of wider track shoes. The overall length of the tank was 26 ft. 5 in., to which the tail had added 6 ft. 1 in. in the case of the earlier marks. The width overall was 13 ft. 6 in., being 3 in. less than that of the earlier marks. The petrol capacity of Mark IV was 70 gal. as against 46 gal. in the earlier patterns. The estimated mileage without refilling was 23 for Marks I, II and III and 35 for Mark IV. The male tanks all carried two 6-pdr guns and four machine guns, but the Mark IV female tank carried six machine guns as against five in the earlier Marks. The design of the Mark IV was begun in October, 1916. The first machine of this type was produced by Messrs. Foster and Company, Ltd., in March, 1917.

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[1] Appendix III.

[2] Based upon "*British Tanks*," by Sir Eustace H. Tennyson d'Eyncourt, K.C.B. (*Engineering*, September 12 and 19, 1919).

The design of the Mark V was begun in October, 1917. The first Mark V tank was produced by the Metropolitan Carriage and Wagon Company, in January, 1918. The Mark IV had disadvantages which limited its fighting powers. Its officer had to attend to the brakes. Its secondary gears required the services of two members of the crew in addition to the driver. Its engine power on bad ground was inadequate. These defects were remedied in the Mark V. An engine of 150 h.p., which had been specially designed by Mr. Ricardo, and a special epicyclic arrangement which had been adapted by Major Wilson were introduced, thus securing one-man control, improved steering and increased speed. The addition of an observer's turret gave a greatly increased field of view. Means were provided for fixing unditching gear from the inside of the machine and mud chutes for cleaning the track were improved. The petrol capacity was increased to 93 gallons and yielded an estimated mileage of 45 miles. The maximum thickness of armour plate was increased from 12 mm. in the previous marks to 14 mm. in the Mark V. The total weight of this mark in fighting trim showed an increase of 1 ton; the weight of the Mark V male tank being 29 tons and that of the female tank 28 tons. It was a serious drawback to the Mark V tank that its ventilation was extremely faulty.

The design of the Mark V* was begun in February, 1918, and the first standard machine was produced by the Metropolitan Carriage Wagon and Finance Company in May, 1918. It had 6 ft. added to its middle length, enabling it to carry infantry in addition to the crew and increasing its trench-crossing power by 3 ft., viz., to 13 ft. as against 10 ft. in the case of previous tanks. Its estimated mileage, without refilling, was 40. The total weight in fighting trim of the male Mark V* was 33 tons and that of the female was 32 tons.

Design of the Mark V** was begun in May, 1918, and the only machine made was produced by the Metropolitan Carriage Wagon and Finance Company in December, 1918. It had a more powerful Ricardo engine of 225 h.p. The weight of the male tank was increased to 35 tons and that of the female to 34 tons. Its petrol capacity was 200 gals. with estimated mileage of 67 miles. The Mark VI which was to have one 6-pdr. in front instead of two in sponsons never got beyond the design stage.

The design of the Mark VII was begun in December, 1917. The first standard machine was produced by Messrs. Brown Bros., Edinburgh, in July, 1918. Its length overall was 29 ft. 10 in. and its width was 13 ft. 9 in. The maximum thickness of its armour was 12 mm. Its petrol capacity was 100 gallons with an estimated mileage of 50 without refilling. Its trench crossing power was 10 ft. Its total weight was 33 tons. It was provided with a 150 h.p. Ricardo engine and the Williams-Janney variable speed gear. An electric self-starter for the engine was first used on this machine.

Design of the Mark VIII "Liberty" tank was begun in December, 1917. The first machine was produced by the North British Locomotive Company in October, 1918. The maximum thickness of its armour was 16 mm. Its total weight was 37 tons. Its length was 34 ft. 2½ in.

and its breadth was 12 ft. 4 in. Its trench-crossing power was 14 ft. Its height was 7 ft. 6½ in., an increase of 2 in. over previous types. Its 300 h.p. Ricardo engine was in an entirely separate compartment from the general interior of the tank, which was occupied by the officers and the gunners. The fighting chamber was in front of the machine and partitioned by a bulk head from the engine room at the rear of the machine. Ventilating fans prevented fumes or heat from the engines from entering the fighting chamber. The track pressures were kept low. The sponsons were hinged and on roller bearings so that they could be moved by hand from within the machine. Mark VIII* with an overall length of 44 ft. was designed but was not put into production.

The first of the lighter or medium tanks was Medium Mark A. the "Whippet," the design of which began in December, 1916. The first machine was produced by Messrs. Foster and Company, Ltd., Lincoln, in October, 1917. It was 20 ft. long, 8 ft. 7 in. wide and 4 ft. 6 in. high. The maximum thickness of its armour plate was 14 mm. and the minimum thickness was 5 mm., *i.e.*, 1 m. less than the minimum in all the heavy tanks. Its trench-crossing power was 7 ft. Its petrol capacity was 70 gallons with an estimated mileage of 80 miles. It carried four machine-guns and a crew of three. Its total weight was 14 tons. Each track was driven independently, two independent engines and sets of transmission gears being used. The engines were 4-cylinder Tylor engines giving 45 h.p. each.

The design of the Medium B "Whippet" tank was begun in June, 1917. The first standard machine was produced by the Metropolitan Carriage Wagon and Finance Company in September, 1918. It was 22 ft. 9½ in. long, 9 ft. 3 in. broad, 5 ft. 9½ in. high and had a trench-crossing power of 8 ft. The minimum thickness of armour plate was increased to 6 mm. Its petrol capacity was 85 gallons for 65 miles. Its total weight was 18 tons. An improved fighting chamber was obtained by placing the engine further back. The machine guns were placed in the turret, as in the Mark VIII, thus providing ample head room. It carried four machine guns and a crew of four men. The engine of the Mark B was the 4-cylinder 100 h.p. Ricardo engine.

The types described above were all fighting tanks, the heavier designs weighing between 27 and 37 tons, the lighter machines, built for speed and mobility weighing from 14 to 18 tons. The gun-carrying tank, design of which began in July, 1916, was intended for transport. It was built to carry medium weight artillery and ammunition. The first machine was produced by the Metropolitan Carriage Company in January, 1917. Its length overall was 30 ft. without tail and 43 ft. with a tail. Its width overall was 11 ft. 6 in. and its trench-crossing power was 11 ft. 6 in. The thickness of its armour plate was 8 mm. Its petrol capacity was 80 gallons which yielded 35 miles. Its engine was the 6-cylinder 105 h.p. Daimler. Its weight was 27 tons unloaded and 34 tons when loaded with gun and ammunition.

Design of an infantry supply tank (Mark IX) began in September, 1917. While it was being developed this class of machine was provided by the adaptation of fighting types as they became obsolescent. Some

machines of Marks I, II and IV were so modified as supply tanks. The first Mark IX tank was produced by Messrs. Armstrong Whitworth in June, 1918. Its total weight was 27 tons unloaded and 37 tons when loaded. It was 31 ft. 11 in. long, 8 ft. 1 in. broad and 7 ft. 8 in. high. The maximum thickness of its armour was 10 mm. Its petrol capacity was 100 gallons, with an estimated mileage of 42 miles. Its trench-crossing power was 12 ft. 6 in. It was specially designed for carrying infantry (50 men) or supplies (10 tons). A maximum cargo space 13 ft. 6 in. by 5 ft. 5 in. was secured in the centre by moving the transmission gears to the rear of the machine and the engine well forward. The engine gear box and epicyclic gear were similar to those of the Mark V. The crew was reduced to four as against eight in all the prior types.

The supply tractor, based upon the tank and intended for general cross country purposes, was about to materialise at the close of hostilities. Certain machines had also been adapted for special uses, *e.g.*, some were fitted with cranes for purposes of salvage. In addition, it has been seen that Marks V* and VIII were built to carry infantry as well as to enter into action.

III. The Conversion of Industrial Plant to Tank Manufacture.

During the first two years of tank production the work of erecting the machines was entirely restricted to the two firms with whom the original contracts had been placed in February, 1916, by far the greater number being erected by the Metropolitan Carriage Wagon and Finance Company.

The most obvious source of supply, the locomotive workshops, was closed to tank production during this period by arrangement with the Railway Materials Department. During 1918 this arrangement was relaxed and two well-known firms of locomotive builders were added to the list of tank erectors, and locomotive builders, in addition to general engineers and engine builders, were employed upon making clutches and epicyclics.

The class of manufacturer engaged upon tank-parts was extremely varied, and in many instances the firms employed needed special training for the purpose. Contracts for bushes, gauges, etc. were placed with makers of motor accessories. Epicyclic gears and bushes were made by a firm of printing machine makers. Contracts for gear boxes and clutches were placed with a firm of petrol engine makers for motor buses. Bridge-builders and ship-builders were included among tank contractors. Boiler makers produced tank hulls. Makers of plant for bakeries turned over to engine production, makers of safes to the manufacture of tank plates and fittings.

IV. The Main Difficulties of Supply.

Production of tanks began at a time when the resources of the country were already highly organised for the manufacture of other classes of munitions. Hence, men, materials and machines for the manufacture of the novel weapon were all obtained in keen competition

with the demands of well-established industries. Uncertainty as to the ultimate success of the new weapon limited the numbers ordered at the very first and caused delay in placing continuation orders, thus enhancing the difficulty experienced in obtaining material and retaining labour.

The amount of labour required was small in relation to the tonnage involved, and the demands of the contractors were met by the Labour Supply Department; but sometimes labour tended to drift away from tank erection owing to a failure in the continuity of output of components. The absence of any reserve of raw material occasionally broke the continuity of the work. Much experiment and practice were needed for making the high-class steel castings for links. Inadequate machining facilities taxed the ingenuity of the supply officers. Machines had to be adapted, or specially designed, while the shortage of machine tools was felt acutely.

Continual difficulties arose from the flood of alterations and modifications made in design during manufacture. Design was never in advance of construction. Output was often checked through lack of precise specification. Frequently, alteration to one part involved unforeseen changes in other parts during manufacture. The pressure under which designs were produced and the haste with which production had to be pressed forward involved serious wastage of material and energy. The impracticability of fixing a definite price beforehand for work subject to constant modification gave rise to serious dissatisfaction among contractors, when, in accordance with the general policy of the central contracts department of the Ministry, orders were given to proceed pending a settlement of prices.

The provision of an adequate supply of spare parts constituted a grave problem. The supply officer (Colonel Stern) was originally of opinion that spare parts were required mainly for training tanks while fighting tanks were to be regarded as projectiles which were used up in their employment. Military authorities, estimating the wastage of machines at a lower figure, demanded spare parts for fighting-tanks in numbers equal to those provided for training-tanks. This demand involved a complete re-arrangement of contracts during the summer of 1916. The enormous scale of the military demands for spare parts in the spring of 1917 threatened to bring the output of new machines to a complete standstill. Experience, however, proved these demands excessive, and they were reduced by five-sixths of the original proportions. A liberal allowance of spare parts was, however, always required concurrently with the supplies of tanks. The life of certain items was only 100 tank miles. The demand for renewals was exceedingly heavy and the supply of replacement parts as against the supply of new tanks called for constant attention. It was not possible to foresee the periods when demands for spares would be increased by reason of the engagement of tanks in battle; nor was it possible to accumulate considerable reserves. Emergency measures had to be adopted to balance output of tanks with supply of spare parts, and thus unforeseen conditions in the field seriously affected production at home.

V. Summary.

The project for evolving a mechanical engine of war was definitely formulated in January, 1915. The development of a satisfactory pattern and manufacture of the first sample machine was the work of the succeeding twelve months. Although it was intended for land service, its development was due to the Admiralty, a Department whose organisation lent itself to the speedy development of a complex machine requiring for its inception considerable elasticity of treatment.

There followed a year of experiments in tank production as well as in tank tactics. The War Office awaited the results of experience in the field before formulating its demands. Consequently, tanks were ordered in numbers too small to allow for the due development of the organisation for production. In the meantime, while the supply of comparatively small numbers was being organised, the conditions which had to be overcome by the new weapon were increasing in difficulty. On the one hand, British artillery preparation, increasing with the augmentation of shell output, broke up the ground over which tanks had to advance. On the other, the enemy's lines of defence were greatly improved and deepened after the battle of the Somme. The "blasting" tactics then employed by the British were met by the creation of defences which covered a depth of twelve kilometres, and made more remote the possibilities of a break through. The experience of the French, however, whose first tanks proved a failure, justified the caution of British military authorities in testing the utility of the earlier marks of machines in isolated actions against individual strong points before they employed the new weapon as a reliable arm in large formations, and as an integral element in their scheme of warfare. The objection of the military authorities to the production of any type in large numbers before standardisation was achieved, prolonged this experimental stage, and the absence of any distinct division between experimental and bulk manufacture tended in the same direction until the summer of 1917. Experience with Mark IV machines which were produced in numbers exceeding the formal demand, but all eventually took the field, proved the practicability of supply in large numbers at an earlier stage than was generally accepted. In the meantime, however, output was gravely hampered by administrative difficulties and the year 1917 was described as a year lost with regard to tanks. Repeated efforts to speed up production and to improve co-operation between the producers and users of the new weapon met with mediocre success. The most noteworthy administrative changes during this time were the establishment of various committees as a means of ensuring adequate co-operation. While the administrative position was recognised as the root cause of failures in output, it was not until the summer of 1918 that the complete internal reorganisation of the supply department set the work of supply upon a sound basis. The emergency arrangements, which had been established to deal with an experimental weapon in the early and uncertain phases of production were then superseded by an organisation better suited for the supply of an established weapon for which a definite and continuous demand existed.

The change in methods of administration was effected with considerable difficulty and was hampered by the need for continuous output. Experience had proved that both output and inspection suffered from the combination of these two duties in a comparatively small number [1] of inspectors or progress officers. Estimates, based entirely upon contractors' figures, with a margin for default, had failed in reliability. Only the personal intervention of the Minister ensured production to meet the immediate requirements of the Tanks Corps in the spring of 1918. The re-organisation of the supply department in the following August was accompanied by a large increase in staff to secure efficiency. The new controller was in a position to apply to future production not only his own knowledge of the realities of manufacture, but also the experience and resources attained by the Ministry in regard to other engineering problems. The establishment of the Tank Board in 1918 completed the re-arrangement of administrative organisation and at the date of the Armistice the supply of tanks in unprecedented numbers was anticipated with good hope of fulfilment.

A complex and entirely novel engine of war had been created in a single year. Within nine months, its appearance in numbers in the field had caused a dramatic surprise, whose moral results are difficult to define. Manufacture in thousands was undertaken during the next two years under enormous difficulties. The general shortage of labour, materials, and manufacturing capacity was keenly felt in the supply of a new store, which came into production at a late date and fell into disrepute or rose in favour with the varying fortunes of its appearances in action. Nevertheless, by the end of the war, over 2,500 machines had been made and issued,[2] the original tank had been developed and improved with experience, and there was a clear prospect of still more successful production upon an enormously increased scale.

[1] The manufacturing programme for 1918–19 involved the employment of some 4,000 contractors and sub-contractors, and an expenditure of £80,000,000. but the whole staff engaged upon inspection and progress duties was 380.

[2] For the detailed figures of output see Appendix VI.

APPENDICES

APPENDIX I.

(CHAPTER I., p. 3.)

Extract from a Memorandum by Lt.-Col. Maurice P. A. Hankey, dated 28 December, 1914.

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8. In the ancient wars all kinds of devices were adopted to attack the enemy's ramparts when an *impasse* occurred. Special trains of battering rams, catapults, movable towers on wheels, with draw-bridges, escalading ladders, Greek fire, the testudo or "tortoise" pent houses, special shields and armour were among the means employed. Later on siege trains, sapping and mining, and hand grenades superseded the old devices, and these are still employed, though they are less effective against modern methods of defence.

9. Is it possible by the provision of special material to overcome the present *impasse* ? Can modern science do nothing more ? Some of the following devices might possibly be useful :—

(*a*) Numbers of large heavy rollers, themselves bullet-proof, propelled from behind by motor engines, geared very low, the driving wheels fitted with "caterpillar" driving gear to grip the ground, the driver's seat armoured, and with a Maxim gun fitted. The object of this device would be to roll down the barbed wire by sheer weight, to give some cover to men creeping up behind, and to support the advance with machine-gun fire.

(*b*) Bullet-proof shields or armour. Sir Edward Henry has a most interesting bullet-proof shield designed after the Sydney Street affair. The War Office, however, consider it too cumbersome for use in the field. Possibly some similar, but less cumbersome, contrivance might be designed for use where the trenches, as at present, are only a few yards apart ; only a proportion of the men need be armed with them, and these would shield others behind, who would be instructed to change places with the shield bearers when the first line of trenches was captured. Lord Esher has informed me that an officer has recently invented a light form of armour that covers the vital organs, and the French are reported in the newspapers to be employing a shield in the Argonne.

(*c*) Smoke balls, to be massed in the trenches before an advance, and to be used if the wind is in a favourable quarter. They would be thrown by the troops towards the enemy's trenches to screen the advancing troops.

(*d*) Rockets throwing a rope with a grapnel attached, which are being used by the French to grip the barbed wire, which is then hauled in by the troops in the trench from which the rocket is thrown.

(*e*) Spring catapults, or special pumping apparatus to throw oil or petrol into the enemy's trenches. Sir John French (in his remarks on the recent experiments with burning oil) has asked if some such apparatus could be designed. It will be remembered that in one of their most recent official communiqués the French reported that their troops had been burnt out of their trenches.

10. If these and other methods could be prepared secretly, and no hint of them allowed to leak out until the day or night of the attack, and if rumours were spread and dummy preparations made for an attack elsewhere, *e.g.*, on the Belgian coast, or the Frisian Islands, or in Schleswig-Holstein, these methods might have a fair chance of success. It must, however, be recognised that the preparations would take some months to complete, and they ought to be organised in concert with the French.

11. Is it not possible that a small expert Committee might be able to design devices suitable to the present situation ? If formed it is indispensable that it should include officers of Royal Engineers personally acquainted with the conditions now prevailing at the front. The Committee would have to be given a free hand with a certain amount of money for experiment, and should have full authority to call to counsel any expert required.

APPENDIX II.

(CHAPTER I., p. 3).

Letter from Mr. Churchill to the Prime Minister, dated 5 January, 1915.

My dear Prime Minister,

I entirely agree with Colonel Hankey's remarks on the subject of special mechanical devices for taking trenches. It is extraordinary that the Army in the Field and the War Office should have allowed nearly three months of trench warfare to progress without addressing their minds to its special problems.

The present war has revolutionised all military theories about the field of fire. The power of the rifle is so great that 100 yards is held sufficient to stop any rush, and in order to avoid the severity of the artillery fire, trenches are often dug on the reverse slope of positions, or a short distance in the rear of villages, woods or other obstacles. The consequence is that the war has become a short range instead of a long range war as was expected, and opposing trenches get ever closer together for mutual safety from each other's artillery fire. The question to be solved is not therefore the long attack over a carefully prepared glacis of former times, but the actual getting across of 100 or 200 yards of open space and wire entanglements. All this was apparent more than two months ago, but no steps have been taken and no preparations made. It would be quite easy in a short time to fit up a number of steam tractors with small armoured shelters, in which men and machine guns could be placed, which would be bullet-proof. Used at night they would not be affected by artillery fire to any extent. The caterpillar system would enable trenches to be crossed quite easily, and the weight of the machine would destroy all wire entanglements. Forty or 50 of these engines prepared secretly and brought into positions at nightfall could advance quite certainly into the enemy's trenches, smashing away all the obstructions and sweeping the trenches with their machine gun fire and with grenades thrown out of the top. They would then make so many *points d'appui* for the British supporting infantry to rush forward and rally on them. They can then move forward to attack the second line of trenches. The cost would be small. If the experiment did not answer, what harm would be done? An obvious measure of prudence would have been to have started something like this two months ago. It should certainly be done now.

The shield is another obvious experiment which should have been made on a considerable scale. What does it matter which is the best pattern? A large number should have been made of various patterns: some to carry, some to wear, some to wheel. If the mud

now prevents the working of shields or traction engines, the first frost would render them fully effective. With a view to this I ordered a month ago 20 shields on wheels to be made on the best design the Naval Air Service could devise. These will be ready shortly, and can, if need be, used for experimental purposes.

A third device which should be used systematically and on a large scale is smoke artificially produced. It is possible to make small smoke barrels which on being lighted generate a great volume of dense black smoke which could be turned off or on at will. There are other matters closely connected with this to which I have already drawn your attention, but which are of so secret a character that I do not put them down on paper.

One of the most serious dangers that we are exposed to is the possibility that the Germans are acting and preparing all these surprises, and that we may at any time find ourselves exposed to some entirely new form of attack. A committee of engineering officers and other experts ought to be sitting continually at the War Office to formulate schemes and examine suggestions, and I would repeat that it is not possible in most cases to have lengthy experiments beforehand. If the devices are to be ready by the time they are required it is indispensable that manufacture should proceed simultaneously with experiments. The worst that can happen is that a comparatively small sum of money is wasted.

Yours, etc.,

WINSTON S. CHURCHILL

APPENDIX III.

(CHAPTER I., p. 4.)

Memorandum by Captain T. G. Tulloch on Land Cruisers and Destroyers.[1]

The present *impasse* in the situation from the Belgian Coast to the Swiss Frontier emphasises the necessity of some entirely novel means of attack, in order to break through the enemy's lines. Heavy ordnance is placed on armoured trains and run on rails; machine guns are placed on motor cars and run on roads. The scope of action of both these is limited by the fact that to stop them it is only necessary to place a barrier across, or destroy, the rail or road on which they run, and furthermore their point of attack must always be known.

If a means could be found for mounting either ordnance and/or machine guns on a carriage which could move across country and to the passage of which neither barbed wire nor trenches nor embankments (within such reasonable dimensions as might be expected) offer any hindrance, it would appear that the provision of such a fleet of carriers would confer upon that force which first made use of them, and provided they came as a surprise to the enemy, a power of offensive of vast potentialities, for it would enable the attacker to place himself athwart and enfilade the enemy's trenches, tearing through the barbed wire entanglements on the way, thus opening a road for the supporting infantry and even, eventually, for the cavalry. The point of attack would be unknown beforehand to the enemy, thus making special defensive provisions very difficult.

Quite apart from the question of suitable power of units and road beds, which will be considered later, the technical problems involved necessitate the consideration of the relative merits of (1) the "Land Cruiser" and (2) the "Land Destroyer."

(1) The land cruiser would be fitted with quick-firing guns, searchlights and machine guns, and would carry such thicknesses of armour as would protect the crew from anything but the effects of a high explosive from a gun or howitzer above ordinary field gun size. The question of weight, etc., would prevent any attempt at armouring beyond such thicknesses as would keep out an effective high explosive shell when fired from ordinary field guns, and this could readily be obtained, not by using a single thickness of armour which would resist the effect of such a high explosive field gun projectile attack, but by a system of outer and inner casing of much lighter plating; in fact,

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1 Forwarded to Colonel L. Jackson, 19 January, 1915.

provided sufficient air space is left between and no *surface absolutely normal to the line of fire occur in the design*, it is quite probable that a 7 mm. thickness of suitable plating for both the outer and inner skin will suffice.

(N.B.—This opinion is based on actual experience.)—Intld. T.G.T.

As regards the weapons of offence to be carried on the Land Cruiser, these must be of the automatic type, using graze fuses with projectiles filled with high explosives, and there appears to be nothing more suitable than the new 2-pdr. automatic gun. The number of guns should be four—placed one ahead, one astern, and one on either side, thus bringing a maximum of three guns to bear on any flank or front or four guns if two flanks and a front be the object of attack. With such guns and projectiles the traverses of the trenches would easily be pierced and blown to pieces and the personnel hidden there would be destroyed. The moral effect is also very great, as was shown even with the smaller pom-pom in the South African war. At the same time this gun and projectile is eminently fitted for the direct attack of field guns, having a velocity of 2,200 ft., being automatic in action, and firing at the rate of about 80 rounds per minute, it is difficult to conceive that one such gun, properly protected from the fire of the artillery opposed to it, would have any difficulty in rapidly silencing the opposing battery, the shells of which would be useless against such a combination of velocity and rapidity. As regards an auxiliary armament for the Land Cruiser, there should be one machine gun on either side, to assist in enfilading trenches and to beat off any infantry rush upon the cruiser, a further provision for the same object would be a high tension electric rail round the vessel. The searchlights proposed are, perhaps, a refinement, but one can quite well imagine that the attack of such a machine as described above upon a line of trenches at night time, aided by a searchlight or lights, would be an extremely effective way of turning the enemy out of his positions.

(2) The other alternative is the "Land Destroyer," consisting of a very much lighter carrier and mounting two or three machine guns only. This type might be quite effective for simply turning the personnel out of the trench, but on the very first hit from a field gun it would be put out of action; the armoured cruiser, on the other hand, would only be put out of action by a direct hit from a howitzer or some other projectile above field gun size, and considering the vessel will be on the move, it would certainly be a difficult mark for a howitzer to get a direct hit on.

We now come to a consideration of the carriage and motive power. So far as the carriage is concerned, there seems to be only one principle which can be employed, namely, that the carriage should lay its own road-bed on the principle of the Hornsby-Akroyd caterpillar type, which has subsequently been improved upon in the Holt caterpillar. Details will of course have to be worked out very carefully as regards providing more than two road-beds, so that in case any one becomes destroyed the Landship, whether it be of the armoured cruiser or

destroyer type, can be brought out of action on its other own road-beds. Generally speaking, as it would be necessary to have equal power of speed both ahead and astern and to provide sufficient elasticity and dimensions, it would appear that the principle of arrangement of the Fairlie Twin Locomotive should be used, that is to say, a back-to-back pair of carriages with two independent sets of road-beds and two independent sets of engines, the two carriages coupled up so as to work as one entity.

As regards the motive power, the use of internal combustion engines offers many disadvantages in such a vessel, owing to their complication and also owing to the fact that the machine will have to work in an enclosed plating of armour which will prevent anything in the nature of a radiator, which in the Holt type of caterpillar is of very large dimensions indeed.

The solution of the problem as regards motive power, taking into consideration the fact that the landship will not be required to travel many miles on end, seems to be in the direction of a comparatively small steam boiler, coke fired, actuating a small double-acting, single (or double) cylinder engine, suitably geared to the wheels on the road-bed.

There appears to be no insuperable objection to extending the use of such a general design so as to make it float and propel itself over flooded areas or rivers.

It does not seem practicable to adapt any of the present existing "caterpillars" for the general purpose, and, besides, they are wanted elsewhere.

The quickest way to tackle the problem is to enlist the interest of a thoroughly sound professional automobile engineer and designer who has at his back the facilities for designing offered by a well-equipped drawing office and a factory where the vessels could eventually be built if the design were approved. An artillery and explosives expert, in committee with the engineer, should not take long in getting out a general design of the whole at small expense for ultimate approval for the building of a series of vessels if the design is considered likely to be a practical tactical success. The cost of design and drawings would probably be covered by £200 or so.

The suggestion to form a committee as above described is an essential, as experience shows that every design involving several sciences is bound to be a compromise, each aspect having its limitations.

15 *January*, 1915.

APPENDIX IV.

(CHAPTER II., p. 18)

Memorandum by Lt.-Col. E. D. Swinton on the Necessity for Machine Gun Destroyers.[1]

The Germans, possibly in order to release troops for offensive action on a grand scale elsewhere, have for some time been maintaining and are still maintaining their front in France and Belgium with a minimum of men. They have been able to do this because they have fully realised and exploited the principle that on the defensive numbers of men can be replaced to a very great extent by skilfully and scientifically arranged defences and armament and by machinery. They possess the knowledge, energy and skill to organise such defences thoroughly, and have by now had the time to do it.

By this time their positions consist of a strong front firing line of trench or breastworks backed by a zone which includes, besides communications, a network of subsidiary supporting trenches and points, such as works, houses, which are held by few men and yet provide a great volume of fire in different directions. Some of these works give fire to the front, others run fore and aft and give lateral fire to the right and left against an enemy who may have broken through the front line and seeks to penetrate further. Most are so arranged that if lost they can be enfiladed or bombed.

In this maze behind the front the defenders, unless absolutely paralysed and shattered by artillery fire, have all the advantages. For there the attackers, if they should succeed in penetrating, find themselves fighting without much artillery support, on strange ground, at close quarters with the defenders, who know every inch of the position and have marked every exposed spot, upon which they train their machine guns and rifles and shower bombs.

The chief feature of novelty in the German tactics does not lie either in the preparation of a strip of ground for fighting the attackers at a disadvantage, nor in the use of machine guns, hand-bombs or grenades. It lies in the number of the machine guns employed. And not only is this the chief feature of novelty; it is the factor which has done most to make possible the economy of men practised by the Germans; it is also the chief factor which has rendered abortive our attempts to penetrate their positions.

So far, we have in all our offensive efforts been unable, with our guns, to shatter the German defensive zone to its full depth over any considerable length and so blast a path for our advance. The machine

[1] Submitted to Chief of Staff, 1 June, and forwarded by Sir John French to the War Office, 22 June, 1915.

guns have not been neutralised, and it is our infantry, either caught up in wire, in the open, or collected in the enemy's trenches, that have had to suffer from the undivided attention of these weapons shooting from protected and concealed positions. We have, so far, been unable to oppose anything to them but the bodies of our assaulting infantry.

Machine guns have caused most of our casualties in the attack and have stopped our offensive efforts. And machine guns will do the same in future, unless :—

We have sufficient artillery and high explosive ammunition to blast a way through the German positions, trenches, wire (trench mortars, bombs, gas cylinders, land mines, vitriol throwers and machine guns inclusive) preparatory to our assault, or :—

We can have recourse to some other means of destroying these weapons or at least of meeting them on equal terms and diverting or neutralising their action so that it is not directed upon our infantry.

The first alternative is not at present within our power, though it may be so in the future.

The second is believed to be possible through the employment of " Armoured Machine Gun Destroyers " which will enable us to engage machine guns on an equality.

ARMOURED MACHINE GUN DESTROYERS (*General Description*).

These machines would be petrol tractors on the caterpillar principle of a type which can travel up to 4 miles an hour on the flat, can cross a ditch up to 4 ft. in width without climbing, can climb in and out of a broader cavity and can scramble over a breastwork. It is possible to build such tractors. They should be armoured with hardened steel plate proof against the German steel-cored armour-piercing and reversed bullets, and armed with, say, two Maxims and a Maxim 2-pounder gun.

Construction.—It is suggested that they should be employed as a surprise in an assault on the German position to be carried out on a large scale. To enable the element of surprise to come in these machines should be built at home secretly,[1] and their existence should not be disclosed until all are ready. There should be no preliminary efforts made with a few machines, the result of which would give the scheme away.

Preparation for employment.—The machines should be brought up to railheads by train or road, and then distributed at night along the front of action. They should be placed in deep pits, with ramps leading from the rear and out to the front over our parapet, dug as required behind our front line.

Suggested employment in attack.—Say 50 destroyers are available. If they are spaced, say, 100 yd. apart on the average it will enable a front of 5,000 yd., or about three miles, to be covered. The machines

[1] This cannot be done if the country is full of aliens.

being in position ready, the wire entanglements in front of the hostile trenches will be bombarded and cut early in the night before the assault is intended to take place. After this, during the night nothing will be attempted except occasional outbursts of rifle fire to prevent the Germans repairing their entanglements. At dawn of the morning fixed for the assault, at a given signal, the destroyers will start. Climbing out of their pits and over the parapet, they will travel across the intervening space straight for the German lines. If this is 200 yd. away they will cover the distance in 2½ minutes, travelling at the rate of three miles per hour. They can tear their way through any entanglement.

Wherever it has been possible beforehand to locate and mark down machine gun emplacements in the German front line the destroyers will be steered straight at them, will climb over them and will crush them. At other points they climb the enemy's parapet or trench, and halting there will fire at any machine guns located with the 2-pounder gun, and will enfilade portions of the trenches with their Maxims.

It is thought that the destroyers, even if they have not by this time actually accounted for the bulk of the defending infantry, will have succeeded in attracting to themselves the attention of the enemy and most of his fire, so that our infantry, who will leave their own trenches and assault just as the destroyers reach the hostile parapet, will be able to cross the fire-swept zone between the lines practically unscathed.

After the destroyers have started out into the open and all surprise is over, our guns will at once start shelling the enemy's artillery in order to keep down its fire. There will be no need for them to bombard the German trenches.

While our infantry are racing for the enemy's front line the caterpillars will move on through the German defensive zone shooting right and left as they go. Those on the flanks of the section selected for the first assault will turn right and left and proceed along and behind the German defence zone, to enable our infantry on either side of the selected section to advance also. The action of their 2-pdr. guns will be reserved for the German machine guns which cannot be rolled over, especially those in houses. Once through the zone of trenches the destroyers will proceed forwards, backed up by and supporting the first wave of the assaulting infantry, which will be moving forward with them, and followed by the mass of troops forming the main body of the attack.[1]

Employment in Defence.—In defence the destroyers stationed behind the line will move up if the Germans break through at any spot and will act as mobile strong points which can be driven forward right amongst hostile infantry who have penetrated. When no general offensive or defensive action is going on their 2-pdr. guns can be used as mobile anti-aircraft artillery.

[1] They may possibly get forward to within rifle range of the German guns.

The attack, carried out as suggested, will probably result in the loss of a certain number of destroyers, but not many, because the machines will be amongst the defending infantry before the German guns can be warned of their advance.

Many details of design, such as contrivances to enable the destroyers to signal back to our own infantry to attract the enemy's attention, to repel boarders, etc., can be suggested.

Gas operations.—The destroyers will be of great value in gassed areas, since the crews will have their mouths at least 10 ft. above the ground, and not having to march, will be able to wear the most efficient masks, even if of heavy design.

Attack.—In a gas attack the destroyers could possibly move forward just in rear of the first gas cloud, where they would be hidden, in front of the first line of our infantry.

But the employment of gas in conjunction with destroyers would prevent any surprise.

Defence.—The employment of destroyers is obvious.

Engines.—In case the gas should interfere with the engines a small reservoir of oxygen could be carried as has been tried for aeroplanes.

APPENDIX V.

Note on the Adoption of the Name "Tank."

When bulk supply became a matter of practical politics, the name "tank" was adopted alternatively with "water-carrier" in order to ensure secrecy. The idea was carried further by labelling some of the first machines "water-carriers, Petrograd," and the name "water-carrier" was occasionally used during the year 1916. This name had been suggested in October, 1915, by Dr. T. J. Macnamara, Financial Secretary to the Admiralty. As a result of discussion between Colonel Swinton and Lt.-Colonel W. Dally Jones, the name "tank" was proposed at the conference on Christmas Eve, 1915, which accepted it, recommending that the new supply authority should be styled "Tank Supply Committee." The programme for the trial of the "mother" machine in January, 1916, was accordingly headed "Tank Trial."

During the experimental period the name "landship" was most commonly used at the Admiralty, where the committee engaged on developing the design was called "The Landships Committee" from the date of its formation until October, 1915. The name "D.N.C.'s Committee" was then adopted for the sake of secrecy. While the proposals laid before the War Office in January, 1915, were for a "land cruiser" or "destroyer," the military committee then appointed generally referred to trial machines as "caterpillars" or "special armoured tractors," occasionally as "special trench tractors." The name "machine gun destroyer" was adopted as an alternative to "landship" after the receipt of Colonel Swinton's paper in June, 1915. Thus the conference of 29 September considered the armament of "landships or machine gun destroyers." Colonel Swinton discussed the "armouredillo" in October, 1914, the "juggernaut" in June, 1915, the "caterpillar grasshopper" in 1916. The specification put forward by the Armoured Car Division in February, 1915, was for a "gun-carrying war machine." Colonel Crompton directed his first efforts in that month towards evolving a "self-moving armoured fort" or "trench-straddling engine." Sir John French called Colonel Swinton's proposed machine "a species of armoured turret." "Mother Tank" was also styled the "Wilson" from Major W. G. Wilson, the "Centipede" from the trade-mark of W. Foster & Co., or "Big Willie" in distinction to the "Little Willie" or "Juggernaut" design. In fact, the name varied with the conception uppermost in the user's mind, until in September, 1916, the dramatic appearance of the new engine of war gave the word "tank" a novel and permanent meaning in the minds of the British public.

APPENDIX VI.

(CHAPTER VI., p. 78.)

Table showing the Output of Tanks, 1916–18.[1]

The following table shows the number of the various types of machine produced. The total number of fighting machines made before the end of 1918 was 2,544. The supply and salvage tanks produced during the same period were 75. In addition, a considerable number of fighting machines were converted for supply purposes.

CLASS OF MACHINE.	1916.	1917.	1918.	Total.
Heavy Fighting Machines—				
Mark I	150	—	—	150
Marks II and III..	—	100	—	100
Mark IV	—	910	105	1,015
Mark V	—	—	400	400
Mark V*	—	—	632	632
Mark V**	—	—	1	1
Mark VII	—	—	—	—[2]
Mark VIII (Liberty)	—	—	1	1
Total Heavy Fighting Machines	150	1,010	1,139	2,299
Light or Chaser Tanks—				
Medium A. (Whippet)	—	55	145	200
Medium B.	—	—	45	45
Medium C.	—	—	—	—[2]
Total Light Fighting Machines ..	—	55	190	245
Total Fighting Tanks, Heavy and Light	150	1,065	1,329	2,544
Supply and Miscellaneous Machines—				
Gun Carriers and Salvage Tanks	—	45	5	50
Infantry Supply Tanks (MarkIX)	—	—	25	25
Total Supply and Miscellaneous Tanks	—	45	30	75
GRAND TOTAL OF ALL MACHINES ..	150	1,110	1,359	2,619

[1] Figures represent deliveries down to 31 December, 1918, exclusive of fighting machines converted as supply tanks.

[2] Formal delivery of the first machine was made in January, 1919.

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VOLUME XII

THE SUPPLY OF MUNITIONS

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CHAPTER I.

THE USE OF MECHANICAL TRANSPORT IN THE WAR.

I. The First Military Use of Mechanical Transport.

The war of 1914–18 was the first in which motor transport was used to any great extent. Besides conveying food and ammunition and stores of all kinds, motor vehicles were used for the haulage of heavy artillery, and the evacuation of wounded to casualty clearing hospitals, and they also formed the quickest means of bringing up reinforcements. Mechanical transport was introduced into the army supply system in 1911, and its use led to greatly increased flexibility in army operations. From that time horse transport was used solely for distributing. A day's supply was despatched daily from depot to railhead by train. From railhead the motor lorries of the supply column conveyed the stores to refilling points where they were taken over by trains of horse-drawn vehicles for distribution to the troops. Thus there was no accumulation of stores at railhead, so that these points could be changed at from four to five hours' notice, and since the daily run of a motor lorry was about 90 miles, troops could advance to any distance such that the refilling points were within 45 miles from railhead. The system also cleared the roads in the rear of troops of the vast convoys of horsed wagons which used to impede manœuvres under the old methods of supply. For the first time it became possible to provide a distant army with fresh meat and bread.

At an early stage in the commercial development of the motor vehicle, consideration had been given to the needs of the Army. At the Imperial Motor Conference held in London in 1913, military policy had been determined. The steam vehicle was ruled out for army purposes on account of its enormous requirement of water, and the two types of lorry adopted as standard patterns for the Army were both petrol-driven. The plan of subsidising commercial vehicles for transport in time of war was adopted by all the great Powers. In order to avoid the confusion which would have arisen through the use of a large number of types of vehicle, all subsidised lorries were required to be constructed along lines which followed certain fixed principles. The British Government subsidised two distinct types of lorry. Both were petrol-driven, with heavy wheels shod with solid rubber tyres. They carried respectively loads of 3 tons or 30 cwts., and were known as heavy or light vehicles. Thus, when the industry had to be organised in war-time, it was merely necessary to multiply vehicles of the existing types. Standardisation of type and components was of great importance in simplifying the provision of spares, and in expediting repairs and replacements in the field, and had the additional advantage of making it possible for a driver to take charge readily of any vehicle.

II. Vehicles used during the War.

(a) STANDARD LORRIES.

Many of the lorries used in France in the early days of the war were motor buses from the London streets, and convoys consisted of vehicles of miscellaneous appearance, brewers' drays, grocers' vans, and other commercial vehicles, to which no alterations had been made. These were subsequently converted into food and forage-carrying vehicles by the substitution of van-shaped open bodies for the two-decker bus bodies or the commercial vans, and as time went on convoys were composed of vehicles of more uniform appearance.

The mechanical transport of a supply column eventually included some 200 vehicles. Besides those actually engaged in carrying supplies there were large high-bodied workshop lorries, closed store lorries, some four-seater cars, and motor cycles. Each vehicle was equipped with the complement of tools necessary for its own adjustments and for carrying out roadside repairs. Stocks of tyres, spare parts, tools and reserves of all kinds were kept at supply depots. Without the mobile workshops the supply column would soon have become hopelessly crippled. The workshop section of a cavalry supply column consisted of four of these travelling shops and four store lorries. The type employed was usually a Silent Knight Daimler or a Leyland with 40 horse-power engine. Surmounting the chassis was a platform bearing a closed-in body, with the two sides made so that they could be opened out and secured horizontally by wooden supports. The top half of each opening upwards formed an extension of the roof and the lower halves being let down extended the floor space. Inside the body were mounted a lathe, drilling machine, tool-grinding machine, fitters' bench and vices, and the necessary small hand tools. A petrol engine direct-coupled to a dynamo drove the different machines. These mobile workshops were developed at the front by the initiative of the O.C. Workshops, and though they were primarily intended only for running repairs, they were developed in some cases to deal with almost any kind of work, even to forging axles. In some cases floor space was saved by eliminating the stationary petrol engine and employing the engine in the lorry chassis to drive the machines. Increased efficiency was also obtained by the use of trailers designed to carry complete spare engines. When stationary the trailer was used as a fitting, erecting and engine-testing bench. On it was fixed a crane by which the engine could be removed from the lorry chassis and placed for overhaul on the trailer with the minimum expenditure of time and labour. The efficiency of the mobile workshop was of great importance, as obviating the necessity of evacuating the lorries to the base depot for replacement. The necessary spare parts and tools and other workshop stores were carried in the store lorries, which also served as offices for the store-keepers and clerks connected with the organisation of the workshops.

The following standard vehicles manufactured in Great Britain were chosen for military service in addition to those used by the Royal Air Force:—

(1) *3-ton Lorries* :—Albion, British Berna (H. Watson & Sons),[1 2] Daimler, Dennis, Halley,[2] Hallford,[1] Karrier, Maudslay, Napier,[1 2] Pagefield, Thornycroft, Wolseley,[1 2] Straker-Squire.[2]

(2) *30-cwt. Lorries* :—Daimler,[2] Napier,[1 2] Belsize,[2] Straker-Squire.[2]

(3) *Cars* :—Sunbeam, Vauxhall, Austin,[2] Daimler,[2] Singer,[2] Wolseley.[2]

(4) *Ambulances*:—Sunbeam, Austin,[2] Daimler,[2] Napier,[2] Siddeley-Deasy,[2] Wolseley.[2]

(5) *Motor Cycles* :—Douglas, Triumph.

(*b*) SPECIAL VEHICLES.

Special types of vehicles were also used. These included steam wagons, Foden-Thresh disinfector wagons, used for disinfecting soldiers' clothing, water-tank lorries, water-tank trailers, motor chars-à-bancs, anti-poison plant lorries, bacteriological sterilising lorries used in connection with the purification of polluted water, mobile X-ray lorries, and Vickers-Clyno motor cycle machine-gun outfits. Certain vehicles were allocated specially to the Royal Air Force. These were Leyland 3-ton lorries, fitted with a special heavy tender body, Leyland workshop lorries, Crossley touring cars, light tenders and landaulettes, and Phelon & Moore motor cycles and side-cars. Special vehicles were also provided for the Royal Air Force, such as silicol plant lorries, telephone and photographic lorries, the chassis of which were of Leyland make. Special types of trailer were also required for the Royal Air Force for the conveyance of aeroplanes and bombs. These trailers were developed for the conveyance of the large Handley-Page aeroplanes. Owing to the great length and width of the wings considerable difficulty was experienced in moving them from place to place by land, but this was overcome by the construction of these trailers. In spite of their great bulk, these wings are comparatively light, and advantage was taken of this by constructing a light but rigid trailer in which the wings were carried on their edges. The form of construction of the trailer was that of a deep box girder, covered with a waterproof canvas sheet, the rear being supported on springs and axle, with twin pneumatic tyres on each wheel, while the forward end was mounted on the rear portion of a 25 horse-power touring car of which the body was removed, so that a six-wheeled articulated vehicle was obtained. This type of trailer proved highly efficient from the running costs aspect and was also readily handled in traffic.

Tractors for hauling heavy guns along the roads became necessary as the guns used in land service increased in size. Steam engines and four-wheeled drives were mainly used for this purpose. The original 6-in. howitzer of 30-cwt. type was drawn by motor traction,

[1] These makes were allotted for Home Service only.
[2] These makes were acquired to a limited extent only, whereas supply of the remaining makes was continuous throughout the war.

and for the lighter type, introduced in 1916, traction was usually by motor. The 8-in. howitzer equipment could travel at a rate of 12 miles per hour with a motor tractor, but for guns of very heavy calibre railway traction was more usually employed.

(c) Cross-country Tractors.

Cross-country motor traction for guns and ammunition was a development of the war. The germ of the idea is to be found in the armoured cars used by the Royal Naval Air Service in the early months of the war as a support to aeroplanes making forced landings in the Dunkirk area. The early machines were improvised by bolting steel plates to the more vulnerable parts, and heavier cars were afterwards developed by mounting 3-pdrs. on motor lorries. The activities of the Royal Naval Air Service in this direction were extinguished when trench warfare extended to the coast in October, 1914. The idea was developed later in the gun-carrying tanks designed in 1917 for the purpose of taking forward fairly heavy artillery in an advance. These tanks were able to carry either a 4·5-in. howitzer or a 6-in. howitzer, but were in the end used more often for bringing up ammunition, of which they could carry considerable amounts. They were supplied in small numbers in 1917, but their production interfered with that of the fighting tanks and they were never produced in large quantities.[1] In July, 1917, Sir Douglas Haig asked that the production of tanks suitable for supply and for signalling should be considered,[2] but no agreement was reached as to the form these tanks should take. Experimental work on this type of vehicle was begun by Colonel Newton at the end of 1917, under the auspices of the Mechanical Warfare Department, and independent research was conducted by other departments of the Ministry, resulting in the production of designs such as the Roller Track Wagon, which was intended to carry a load and also to pull a gun over broken ground.[3]

The shortage of horses, which began to be severely felt in the spring of 1918,[3] when open warfare was renewed, made the development of motor transport for guns of all classes, both on the road and across country, a matter of urgency.[4] In April, 1918, the question was considered of providing motor transport for the smaller types of gun, either as a substitute for or an auxiliary to horse traction, with the object of saving personnel, horses, and horse food. One tractor with two men could take the place of eight horses and eight drivers in hauling the 60-pdr. gun.[5] During the summer the idea was further developed, and in August the War Office issued a specification for an internal combustion engine track lorry for the conveyance of equipment, supplies, and possibly machine gunners across country. The chief conditions to be fulfilled were that the lorry must be able to carry its rated load both on the road and over irregular and soft ground, up a gradient of 1 in 4 on a hard surface, and, fully loaded, across a 4-ft. trench, the sides of the vehicle to be proof against rifle bullets.[6] It was, however,

[1] Hist. Rec./R/1940/34.
[2] Vol. XII, Part III, pp. 52–4.
[3] Hist. Rec./H/1920/3.
[4] M.C. 749.
[5] W. 247.
[6] D.M.R.S. 600 G; Hist. Rec./R/1940/39.

impossible to procure any vehicle capable of carrying its rated load satisfactorily both on metalled or paved roads and across soft country,[1] and attention was directed to the problem of cross-country traction. The great demand for internal combustion engines for other purposes made it necessary to use standard automobile engines.

III. Some Notable Developments in Design.

A committee of the Ministry was formed in May, 1918, with General Sir Capel Holden as chairman, to co-ordinate the work already being done on motor traction for guns, and to explore the possibilities of development. Three patterns were then under consideration: the Newton (semi-tank) tractor, the Fordson tractor, and the Saunderson tractor. The first was not at that time ready for trials, and both the Fordson and Saunderson, which were originally designed for agricultural work, were found to be incapable of hauling guns over broken ground, owing to the small size of their front wheels. In July, after holding several trials, the committee proposed to use 55 horse-power Holt tractors for the 60-pdr. guns, and an 18 horse-power tractor of the same make for light field guns. These had to be procured from America, the opinion of the committee being that in view of the difficulty of getting supply on a large scale from British manufacturers of any new type of tractor, for which designs were non-existent, the only hope of meeting the wishes of the Army Council was to obtain deliveries from America of these two types. It transpired that these were obsolete and had been replaced by a 10-ton and 5-ton model respectively, and vehicles of these types were ordered for trial in August, 1918.[2]

Experiments were continued by the committee on the carriage of guns on tractors and the traction of ordnance generally. In a final report in October, 1918, they recorded the opinion that the 10-ton model caterpillar tractor already ordered would meet all requirements for the 60-pdr. gun, carriage and limber, and the 5-ton tractor could draw the 60-pdr. ammunition wagon. This wagon could also be drawn on the road or other firm ground by the Fordson tractor, already largely used for agricultural purposes. With regard to the light field equipment the problem was not so easy of solution, for it involved a moderate average speed on the road, with the ability to maintain a comparatively high speed for a short time, the power to cross country at least as well as a team of horses, involving an engine power of 55 to 60 horse-power, and the ability to manœuvre. These conditions were not met by any type of tractor then in existence, but the committee thought that the Newton caterpillar tractor, which they had not actually tried, had possibilities for cross-country work with the 18-pdr. and 4·5-in. equipment.[3] This tractor was fitted with caterpillar tracks and was designed to take standard commercial engines and an adaptation of a conveyor chain which was in commercial use. It was hoped

[1] This difficulty, for instance, prevented the utilisation of the "Trench Warfare" *pedrail* caterpillar as a lorry. (See Vol. XII, Part III, p. 31.)
[2] *W. 247*; M.C. 677.
[3] M.C. 677.

by this means to obviate the two main problems of tank manufacture —the provision of special track links and engines.[1] The Newton tractor was developed during the autumn of 1918 to meet the needs of the Army Council but did not actually come into supply before the Armistice.

The K tractor with trailer was designed to carry the Holt tractor in working order, so that it could be transported rapidly and without wear and tear from landing ports to scenes of operations. The K tractor was constructed from various units of an A.E.C. lorry, converted to draw a large "crocodile" trailer. This trailer could also be towed by other types of tractor, when fitted with a fore-carriage, used ordinarily to carry the heavy steel ramps over which the caterpillar climbed to and from its position on the trailer. The complete unit weighed nearly 20 tons with its load and was 50 ft. by 11 ft., but could nevertheless travel at 8 miles an hour and negotiate narrow lanes and turnings without difficulty. Another special development was the trailer for carrying gun platforms, which was built on the gantry crane principle and was quite unique, being of steel throughout with rubber tyres.[2]

The chapters which follow deal with the production of the various classes of vehicle which have been described above. It has also been convenient to add here brief accounts of the supply of the obsolescent horse-drawn vehicle and of the pedal bicycle, the demand for which increased towards the end of the war.[3]

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[1] Hist. Rec./H/1600/14.
[2] Hist. Rec./H/1920/3, pp. 15*–17*.
[3] See Chap. V.

CHAPTER II.

SUPPLY UNDER THE WAR OFFICE, 1914–1916.

I. The Organisation of Home Supplies.[1]

(a) Position at the Outbreak of War.

At the outbreak of war, responsibility for providing and inspecting mechanical transport vehicles for the Army was centralised in section Q.M.G.5, part of the Directorate of Transport and Movements of the War Office within the department of the Quartermaster-General. In peace-time, the functions of the section in this respect were divided between a Mechanical Transport Committee concerned with the development of design and experimental work, and a Chief Inspector of Subsidised Transport, whose duties included the registration and subsidising of mechanical transport as well as the inspection of these vehicles. The actual inspection of service vehicles was effected by the Home Mechanical Transport Inspection Branch of the Army Service Corps at Aldershot.

The committee exercised technical control over the construction and maintenance of the vehicles, kept in touch with the general development of mechanical transport, and investigated the suitability of new types and devices for military purposes. It was also responsible for preparing the specification of the subsidised lorries, for dealing with manufacturers in regard to the construction of experimental vehicles, and for carrying out trials. Manufacturers, whose initial vehicles passed the trials, were permitted to manufacture others of the same type for disposal to private customers. Under the War Department subsidy scheme, such vehicles were available for war service in case of emergency, and the owners became entitled to a subsidy of £110 per vehicle spread over a period of three years, on the understanding that the vehicle would continue to be enrolled, that it would remain in the United Kingdom and the property of the original owner, and that it should be maintained in a thoroughly serviceable condition. The War Office was entitled to purchase the subsidised vehicles on certain defined terms on mobilisation. Certain miscellaneous conditions were also applied.[2]

The Chief Inspector of Subsidised Transport maintained the register of subsidised vehicles and was responsible for the periodical inspection of these vehicles by officers of his department, in order to ensure that they were maintained in good running order in accordance with the subsidy conditions. By a private arrangement between the Chief

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[1] Hist. Rec./H/1920/2.
[2] For a copy of these conditions, see Hist. Rec./H/1920/2.

Inspector of Subsidised Transport and the main manufacturing firms, the sales of all lorries suitable for military purposes other than those already subsidised were recorded in a confidential register. In the skeleton scheme of mobilisation these vehicles, as well as the vehicles under subsidy, were allocated to Army units. The number of mechanical transport vehicles of every description actually in the service on the declaration of war was about 200 all told. All the subsidised lorries, numbering some 700, were then taken over by the War Office and allocated to Army units. The country was divided into areas, to each of which was allotted a certain number of the Chief Inspector's travelling staff, which was composed of regular Army Service Corps officers, supplemented by newly commissioned officers, who before the war were intimately connected with the motor trade. The senior officer in each area was notified of the numbers and types of lorries which were to be impressed from time to time and the places to which they were to be sent, and in this connection the confidential register proved invaluable. Lorries engaged upon the transport of foodstuffs and upon other essential public services were exempted from impressment so far as was possible.

In accordance with a previous arrangement, the Mechanical Transport Committee ceased to exist when mobilisation was ordered. The staff of the committee were transferred to the Chief Inspector of Subsidised Transport, who became entirely responsible for supplying and inspecting all mechanical transport and also for providing the necessary personnel, excluding officers. Shortly afterwards the Inspectorate was converted into a distinct section under the Quartermaster-General, styled the Mechanical Transport Branch or Q.M.G.3. The staff of the branch was exceedingly limited and depended upon draughtsmen drawn from Army Service Corps units for the preparation of drawings. This work was supervised by the inspecting officers of the branch, who also applied their special technical knowledge to drawing up specifications.

(*b*) Arrangements for Developing Manufacture.

Whilst the impressment of second-hand vehicles was proceeding, the quantity production of new vehicles was taken in hand. The first step was the limitation of each maker of repute to the manufacture of one of his own standard heavy makes in each case, and in some cases to one of his standard light makes also. The full output of these standard vehicles was supplied to the War Office at a figure agreed upon between the impressment officers and the makers, and ratified by the War Office. Cars and motor cycles of special makes were also obtained from manufacturers, the types and makes being limited as much as possible, compatible with requirements, in order to reduce the variety of spares. No actual contracts were entered into with firms at the time, but reliance was placed upon the system of impressment for securing each vehicle as it was made. The manufacturers co-operated loyally with the War Office in the matter of supply and endeavoured to increase output rapidly.

All vehicles were inspected before delivery by officers of the Department, who also made out "impressment" notes in order that payment could be effected. This system of fixing prices and payment by impressment notes was also applied to special types of vehicle as well as to the provision of bodies and other parts. Payments were at first made by the paymasters of the various military commands on receipt of the impressing officer's copy of impressment notes, the receiving depot's copy being subsequently obtained in support. Subsequently payment was centralised in the War Office by an arrangement whereby all "payment" copies of impressment notes were rendered to the Finance Department covered by a copy of a letter sent by the Mechanical Transport Branch of the War Office to the firm instructing them to proceed with the supply at the price ratified. When the production of vehicles had settled down to a steady output, it was decided that a contract branch of the War Office should arrange definite agreements for the supply of all mechanical transport vehicles and bodies, and the normal method of payment was then introduced. Normally the Quartermaster-General's Department was responsible for framing estimates of probable requirements, for deciding as to the type of article to be bought, and for inspecting, storing and issuing it after it had been bought by the Contracts Department. The duty of the latter department was to find fresh sources of supply and to determine in what manner the goods could be most efficiently and economically bought. In practice, however, the preliminary arrangements with the firms were carried out by Q.M.G.3, and the Contracts Department acted rather as an executive authority for putting into proper form and arranging the settlement of financial details of contracts which Q.M.G.3 in fact placed and supervised.[1]

The contract method may certainly have resulted in some saving in expenditure where there was recourse to competitive tendering, but by reason of the slower action in placing orders as compared with the previous procedure, much time was lost in the production of supplies; moreover, it was only in the case of special types of vehicles and such articles as bodies that tenders could be invited, as the main items of supply were vehicles of proprietary makes, in the supply of which competition was impossible.

Defects in vehicles brought to light by service conditions were notified to manufacturers, and alterations were introduced by them as rapidly as possible to overcome these defects. Improvements to vehicles in order to make them more satisfactory for military service were also suggested to and considered by manufacturers and effected when it was decided that such were practicable and would prove efficacious.

In the summer of 1915, the output of lorries was more than sufficient to meet Army requirements,[2] and firms who manufactured vehicles surplus to army requirements at the time were permitted to dispose of them to private customers by obtaining the sanction of the War Office

[1] C.R. 2425. [2] *Ibid.*

in each case. They were also required to notify the War Office of the name and address of all customers to whom such vehicles were sold, and it was stipulated by the War Office that the bodies should be of the War Department pattern or that a body of this type should be stored by each manufacturer for every one of another type fitted to vehicles privately sold. The chassis were of the War Office approved type. The manufacturers were also warned that these vehicles were only released on the understanding that they were liable to immediate impressment should military necessity arise. The necessity did eventually arise for impressing a large number of these vehicles, and in this connection the War Office record of their temporary owners proved invaluable.

The provision of mechanical transport vehicles for the Royal Flying Corps was in the earlier stages of the war undertaken by a separate branch of the War Office (the Inspector of Iron Structures Branch), but subsequently the Mechanical Transport Branch of the War Office undertook the provision of these vehicles. The entire output of the following makes of vehicles was allocated to the Royal Flying Corps, viz., the Leyland 3-ton lorry and workshops lorry, the Crossley touring car, light tender and landaulette, and the Phelon & Moore motor cycle and side-car.

The principal difficulty with which the War Department had to contend in the provision of motor transport was the shortage of labour, due very largely to men of the motor industry joining the Colours. This difficulty was to some extent removed by the scheme for the issue of badges to firms engaged in Government work.[1] As the requirements for aeronautical work increased and the policy of adopting British-made aero-engines instead of those of French manufacture came into force,[2] the practice encroached to some extent on the capacity for producing motor vehicles, as aero-engine makers were in all cases recruited from the motor-building trade. Some re-arrangement of capacity became necessary, and the manufacture of Sunbeam cars was, in May, 1916, undertaken by the Rover Company,[3] thus setting free the Sunbeam Company for aero-engines. Similarly the Daimler Company was transferred entirely to aircraft work, the manufacture of their lorries being undertaken by the Associated Equipment Company.

The progress of supply as well as the quality of the vehicles was very largely the concern of the inspection staff. At first, their work also included the arrangement of purchases. Four areas of inspection were arranged with their headquarters in London, Birmingham, Manchester, and Newcastle-on-Tyne, Glasgow being subsequently substituted for Newcastle. The inspecting staff of the London area worked in close co-operation with the administrative side of the Supply Section of the Mechanical Transport Branch of the War Office, and the senior officer of this staff supervised the operations of the inspecting officers of the other areas, since his close touch with head-

[1] C.R. 2425. [2] See Vol. XII, Part I, Chap. II. [3] 94/MT/1869.

quarters gave him knowledge of policy and decisions, which fluctuated considerably, owing to the rapidly progressive scale of requirements. Maintenance of quality being considered of no less importance than volume of output, a high standard of inspection was fixed at the commencement, and although in the earlier stages this resulted in many rejections, it undoubtedly led to a rapid improvement of the standard of manufacture which correspondingly reduced the number of subsequent rejections.

The inspecting officers of areas not only tested and inspected vehicles, etc., manufactured in their respective areas, but assisted manufacturers in obtaining material, and in this connection an arrangement was brought into force whereby the inspecting officer of one area acquainted inspecting officers of other areas of the material required from firms in the latter areas by the contractors in their own. These firms were then visited by the inspecting officers concerned, and the delivery of the material was hastened by them. The inspecting officers also supervised the manufacture of spare parts in their respective areas and hastened supply. They investigated the position in regard to operatives who were called up for military service, making the necessary recommendations for exemption and badges. This system undoubtedly contributed very considerably to success in production, both under the War Office and later under the Ministry of Munitions. It established friendly relations with all contractors and enabled the supply of vehicles and parts to be well maintained in spite of low priority and difficulties in obtaining materials.

All vehicles delivered were accepted at a Mechanical Transport Depot which was located on mobilisation in Kensington Gardens, and subsequently moved first to Grove Park, S.E., and later to Kempton Park. A depot for the mobilisation of mechanical transport units was located first at Grove Park, S.E., and finally at Bulford Camp. The vehicles required by these units and also vehicles required as reserve or for replacement overseas were indented for on the Acceptance Depot, who completed them with articles laid down as equipment for military vehicles drawn from the Home Mechanical Transport Depot referred to later, and arranged for their convoy to the Mobilisation Depot. Owing to the enormous number of vehicles with which the Acceptance Depot had to deal, a very large organisation came into being at Kempton Park. Roads and covered ways were constructed there, storage accommodation and workshops were provided, and for recording the receipt and issue of every vehicle and stores of all descriptions a large clerical staff was also necessary.

II. Foreign Supplies.

As the war progressed, the demand for lorries and cars for military purposes increased to such an extent that the output in this country was inadequate to meet it. An increasing number of supplementary contracts were accordingly placed abroad, mainly in the United States of America, where purchases had already been made from time to time.

Thus, for instance, immediately after the outbreak of war, orders had been placed for Studebaker and Bain wagons and a special staff of inspectors had been sent out to the United States in September, 1914, to examine these before shipment.[1] Later, trials of American-made vehicles brought into this country by agents of American firms and by the earlier Canadian divisions were carried out under the observation of technical officers of the War Office Mechanical Transport Branch and, as a result, contracts were arranged for the purchase in America of quantities of the following makes, these being considered the most satisfactory of the vehicles tried: Packard, Peerless, Pierce-Arrow, Locomobile, and Saurer. The American-made four-wheel drive lorry, which in these trials gave promise of useful service in connection with the haulage of light artillery and for other purposes, was also ordered in quantities from America. Subsequently, running contracts were placed in America for Peerless chassis, four-wheel drive chassis and Holt caterpillar tractors. The purchase of the tractors resulted from the original importation of a few for trial purposes in connection with the haulage of guns over broken country. Bodies for these American chassis, including the four-wheel drive, were provided and fitted in this country. A quantity of light vans of Studebaker, Willys-Overland, and Garford make were also required from America at various times. It was eventually decided that the introduction of the Ford car and ambulance into the service would serve a useful purpose in many directions, the low cost of purchase and the relatively good performance of these vehicles also being an incentive to their acquisition. At the same time attention had also to be paid to the fact that the output of cars in this country of makes approved for military service was not equal and not likely to be equal to the full requirements. Ford cars and ambulances were first acquired from the firm's stock in this country as and when required, but subsequently a running contract was placed with the firm and arrangements made for them to import from time to time under "blanket orders," components which, together with those obtainable by the firm in this country, enabled them to erect vehicles according to requirements, and allowed a margin for the supply of parts required by the War Office as spares.

In addition to these American purchases, certain comparatively small contracts were placed in Switzerland and Italy. The entire output of lorries from the Berna Company's factory in Switzerland was taken in order to prevent the enemy from obtaining possession of these vehicles. Delivery was made direct from this Swiss factory to the military authorities in France (Paris), but deliveries were very unsatisfactory owing to various difficulties connected with the provision of material, etc., from this country and the agreement was accordingly revised in March, 1917.[2]

Italian contracts for chassis and tyres were chiefly placed through London agents. The types purchased were S.P.A. and F.I.A.T. lorries.[3]

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[1] See Vol. II, Part III, Chap. VII.
[2] See Vol. II, Part VII, p. 20.
[3] *Ibid.*, p. 14.

CHAPTER III.

SUPPLY UNDER THE MINISTRY OF MUNITIONS, 1916–1918.

I. Gradual Concentration of Responsibility in the Ministry.

(a) ARRANGEMENTS FOR SUPPLYING VEHICLES FOR THE ARMY, 1915–1916.

Upon the formation of the Ministry of Munitions in June, 1915, the branch of the Directorate of Army Contracts, which was dealing with mechanical transport as well as with metals, machinery, horse-drawn vehicles, and pedal bicycles, was transferred *en bloc* to the new Department where, in July, 1915, it became Section P.M.1 of the directorate of Munitions Contracts. The actual work of interviewing firms and organising the trade remained with section Q.M.G.3 of the War Department. At first contracts for mechanical transport were signed "for the Director of Army Contracts," so that in respect of these stores the staff of the branch P.M.1 remained technically a part of the staff of the Director of Army Contracts. This practice was, however, soon abandoned, and contracts for mechanical transport vehicles were signed on behalf of the Director of Munitions Contracts.[1] The question of the transfer to the Ministry of Munitions of the whole responsibility for supplying these stores was discussed in September, 1915, but supply was then in a satisfactory state and the War Office organisation was coping adequately with the situation, while there was no apparent clash between the interests of these stores and any others for which the Ministry was responsible.[2] The question was also raised at the time as to whether the Ministry should not assume complete responsibility for the supply of motor tractors necessitated by the new programme of gun manufacture. Since, however, ample supplies of these also were being provided by the War Office, the question lapsed for the time being.

The arrangements made in July, 1915, continued until in the following November the War Office, impressed by the undesirability of the separation between the technical and financial responsibility, and the responsibility for the placing of contracts, began to press for the re-transfer of that part of the Contracts Branch which was dealing with mechanical transport. This was agreed to by the Ministry in February, 1916.[3] It was ascertained, however, in April, 1916, that the War

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[1] *The Transfer of Functions from the War Office to the Ministry of Munitions and the Relations of the Ministry to certain Public Departments.* Part II, p. 5 (Copy in HIST. REC./R/200/2).

[2] HIST. REC./R/1920/8.

[3] HIST. REC./R/200/2.

Office did not accept responsibility for supplying tractors required for certain heavy howitzers ordered by the Ministry in excess of the War Office gun programme. The Ministry accordingly assumed this responsibility, and a new section of the Department of Munitions Supply was established in May, 1916, to undertake this work, and was placed under the direction of Mr. Rainforth as Director of Munitions Mechanical Transport (D.M.M.T.). At the same time the Ministry accepted responsibility for the provision of large supplies of mechanical transport for the Russian Army. Accordingly orders for mechanical transport were being placed both by the War Office and the Ministry and also to a small extent by the Admiralty, chiefly for the Royal Naval Air Service. The whole of the Admiralty supplies were in fact arranged for and inspected by officers of the Royal Naval Air Service.

The situation was much complicated by the practice by which motor manufacturers were employed on other work in addition to the manufacture of motor chassis for which their plant was primarily intended. They were also making aeroplanes, aero-engines, shell and other miscellaneous stores. Under the circumstances it was considered advisable to prohibit the manufacture and sale of motor chassis except under licence, to establish a department for exercising this control, and to take measures for co-ordination between the several departments interested.[1]

On 28 July, 1916, the Mechanical Transport Contracts Committee at the War Office, which had been set up in June of that year for the purpose of advising the Director of Army Contracts, recommended, in view of the difficulties which had arisen, that the Ministry of Munitions should be given sole responsibility for the supply of motor vehicles of all kinds both for the British Army and Allied Governments. Accordingly the War Office agreed on 28 August, 1916, to transfer the responsibility for supply to the Ministry, as from 1 September, 1916. The responsibility for inspection was also to be transferred, but the determination of designs and specifications and of the tests to be applied was reserved to the War Office. In September the War Office, fearing that a divorce of design from production might lead to delay in supply, expressed willingness to transfer responsibility for design to the Ministry on condition that the nomination of officers in charge of design should remain with the War Office.[2]

(*b*) Action to Co-ordinate Mechanical Transport Supply for all Departments.

Supply for the Admiralty remained outside the Ministry organisation until 1 April, 1917. It was then agreed that supply and inspection should be undertaken by the Ministry on behalf of the Admiralty.[3] As time went on other departments, such as the Food Production Department, Post Office, Crown Agents, and the Board of

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[1] Hist. Rec./R/1920/8.
[2] Hist. Rec./R/200/2.
[3] D.M.R.S. 430 N.

Trade (Timber Supply) required mechanical transport in increasing quantities. They, at first, obtained their supplies by direct purchase, often in open competition with the Ministry. At a conference in February, 1918, it was agreed that all departments should pass their demands and all allied demands for mechanical transport to Section Q.M.G.3, which was still responsible for estimating the needs of the Army in this respect. The French Government requisitioned direct on the Ministry of Munitions by a special arrangement, but it was agreed that the Ministry should pass these demands to Q.M.G.3. Demands for spare parts were to be treated in the same way as demands for vehicles, but Q.M.G.3 passed them through the Home Mechanical Transport Depot to the Ministry, instead of direct as in the case of complete vehicles. On receipt of demands Q.M.G.3 considered whether they could be met from stock, and if this could not be done, applied to the Ministry to manufacture additional supplies.[1] In March, 1918, Q.M.G.3 assumed a similar responsibility for supplies of mechanical transport to the American Army.[2]

This procedure was modified at an interdepartmental meeting in April, 1918, when it was agreed that all departments should demand mechanical transport through the Director of Munitions Requirements and Statistics of the Ministry and should obtain their spares from the Officer Commanding Home Mechanical Transport Depot.[3] The Department of Requirements and Statistics, before passing the demand to the Mechanical Transport Department, ascertained that the War Office was unable to supply from stock. To assist supply it was arranged that an interdepartmental committee should meet twice monthly. This committee was reconstituted in May, 1918, as an allocation Sub-Committee of the War Priorities Committee and consisted of representatives of the Admiralty, War Office, Ministry of Munitions, Air Ministry, and Board of Trade (Timber Supply Department), under the chairmanship of Lieut.-Col. C. V. Holbrook, representatives of other departments having a right to attend the meetings when their departments were interested.[4]

The shortage of petrol engines became very marked towards the end of the war, and in September, 1918, the Minister approved the formation of a Petrol Engine Advisory Committee to co-ordinate petrol engine production. The departments interested were the Aircraft Production, Mechanical Warfare, and Mechanical Transport Departments, and the committee was composed of representatives of these three. The duties of the committee were to consider the demands of each department, the available capacity and possible extensions, and the possibility of some adjustment in the various programmes.[5] The first act of this committee was to examine into the supply of stampings and forgings, but shortly afterwards the Armistice terminated their labours.

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[1] D.M.R.S. 430 B.
[2] D.M.T./5/S/9.
[3] D.M.R.S. 430 N.
[4] D.M.R.S. 430 A.
[5] W. 251.

II. Administrative Organisation for Supply and Design.

(a) The Machinery for Supply.

The Mechanical Transport Department of the Ministry was established in September, 1916, under Sir Albert Stanley as Director-General (D.G.M.T.). It was organised in two branches. The Directorate of Munitions Mechanical Transport under Mr. Rainforth (D.M.M.T.) still continued to deal with the design and supply of mechanical transport for the Allies of Great Britain, and certain special tractors for the British forces, while a new branch under Colonel (later Brig.-Gen.) Sir H. Capel L. Holden (D.M.T.), who had been transferred with his staff from the War Office, dealt with design and supply of mechanical transport for the British forces. The inspection staff of the Mechanical Transport Branch of the War Office was transferred to the Ministry, and was amalgamated with the inspection staff of Mr. Rainforth's department as the Directorate of Mechanical Transport Inspection (D.M.T.I.), the Director being responsible to the Director-General of Inspection of Munitions. In October, accommodation became available at the Grand Hotel and the Constitutional Club for all sections dealing with mechanical transport work, and the concentration under one roof of the branches responsible for contracts (P.M.4) and finance (M.F.11), as well as those for supply and inspection, had been effected by the end of November.[1]

To secure co-ordination between the branches bi-weekly meetings were held in the Director-General's rooms at which questions of policy and matters affecting more than one section of the organisation were discussed. The organisation under the Director of Munitions Mechanical Transport was used to keep in touch with progress made with extensions, and he also dealt with other departments of the Ministry on questions relating to new buildings, additional plant, and the provision of tools. Relations with the Admiralty and the Royal Flying Corps were maintained through the medium of a liaison officer appointed by each of these authorities, and in all matters of ordinary administration this method, although somewhat slow, usually worked satisfactorily.[2]

In December, 1916, Sir Albert Stanley relinquished his appointment as Director-General and the post remained vacant until 26 February, 1917, when Mr. Percy Martin was appointed. He had previously, on 6 February, been appointed Controller of Petrol Engine Supply, so that his duties embraced control of the supply of aircraft engines as well as the control of the supply of mechanical transport. He later took the title of Controller of Mechanical Transport, but his office lapsed in November, 1917, when the department was reorganised and placed under the control of Lieut.-Col. Holbrook.[3] During the time Mr. Martin was responsible for the supply of mechanical transport he dealt personally with matters of policy and devoted special attention to the supply of engines for mechanical transport vehicles, but the

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[1] Hist. Rec./H/1920/1. [2] *Ibid.* [3] Hist. Rec./H/1920/2.

executive and administrative work in connection with the provision of supplies generally was controlled by the Director (later known as the Assistant Controller) of Mechanical Transport. It was decided in April, 1917, to abolish the section known as the Department of Munitions Mechanical Transport, and to absorb its duties and part of its personnel in the remaining sections concerned with supply and inspection.[1]

Upon the formation of the Munitions Council in August, 1917, the Mechanical Transport Department was included in the Council Group " Engines " under the control of Sir Arthur Duckham.[2] Shortly afterwards, in November, 1917, Lieut.-Col. C. V. Holbrook, who was at this time Director of Mechanical Transport Inspection, was given control of the Mechanical Transport Supply Department in succession to Brig.-Gen. Sir H. Capel L. Holden. Colonel Holbrook still continued to act as Director of Mechanical Transport Inspection, but the inspecting staff remained under the Controller of Munitions Inspection. It had been arranged in September, 1916, owing to the composite nature of the work of the Inspection Department, that the staff should report to the Director-General of Inspection as regarded inspection and to the Director-General of Mechanical Transport as regarded supply.[3]

Under Colonel Holbrook, the Mechanical Transport Department was reorganised in two branches concerned respectively with questions of supply and with technical matters. A notable feature of the Supply Branch was the Production Section. Its main duties were to assist the supply sections in regard to sources of supply, to advise as to what components should be made the subject of Ministry supply to contractors, and to suggest the use of substitutes for materials or components which contractors found difficulty in obtaining. It dealt with all other departments of the Ministry of Munitions, and obtained the necessary assistance for contractors in all their difficulties in regard to priority, materials controlled by other departments of the Ministry, and the supply of labour. It was also responsible for compiling records as to the position in regard to demands and deliveries under contracts and sub-contracts, and for keeping the area inspecting officers acquainted with all delays that occurred, thus enabling them by personal visits to the contractors to speed up those contracts which were most urgently required and behindhand.[4]

(*b*) DESIGN ORGANISATION.

The Ministry was responsible for the design as well as the supply of mechanical transport vehicles. Brig.-Gen. Sir H. C. L. Holden relied upon his own technical knowledge and wide experience of mechanical transport, and, aided by a few draughtsmen, dealt

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[1] HIST. REC./H/1920/2.

[2] It subsequently became part of the " Warfare " Group.

[3] D.G.I.M./Gen./016.

[4] For a detailed description of the working of this system, see HIST. REC./H/1920/3; HIST. REC./R/263/23.

personally with all technical matters. Under Lieut.-Col. Holbrook such matters were assigned to the special Technical Section (D.M.T. (T)). As far as vehicles of standard make were concerned, the section's work consisted mainly in settling the technical details involved in arranging for modifications and additions required from time to time as a result of the performance of the vehicles under war conditions. A record of all modifications, and detailed drawings and specifications of all vehicles were kept. The drawings and specifications which usually accompanied demands for special vehicles were scrutinised by the Technical Section and revised if necessary, before issue to contractors. In some cases the details given for such vehicles were very meagre and detailed drawings had to be prepared by the section. When the initial supply of such vehicles or bodies had been arranged and the sample machine had finally been accepted as suitable by the demanding department, the contractors were called upon to provide the section with a detailed drawing and specification of the article in its complete state. This enabled the Supply Department to obtain any further vehicles of the same type from any manufacturer with available capacity, and did not restrict the department to the one manufacturer who had in conjunction with the Technical Section formulated the design of the special vehicle.

With regard to spare parts and accessories, for which demands emanated from the Home Mechanical Transport Depot, the latter furnished their own drawings and specifications with the demands, except where the demand covered makers' listed articles. It was found, however, that owing to the restrictions in supplies of materials, it was frequently impossible to produce according to the drawing and specification. Consequently the Technical Section, who kept in close touch with the Production Section and knew the conditions with regard to material throughout the country, produced alternative drawings and specifications which enabled the supply to be made. In some cases no drawings of the spare part required were available, in which case an accurate sample was obtained from the depot, and from this the Technical Section prepared drawings and specifications. This method was used to a great extent when the shortage of shipping tonnage made it imperative to concentrate every effort on the production in this country of spare parts for American-made vehicles which had previously been obtained almost exclusively from the United States. The section also dealt with all questions of a technical nature raised by manufacturers, and considered all inventions or devices applicable to mechanical transport submitted to the department either directly or through the Munitions Inventions Board.

III. The Formulation of Requirements.

(*a*) Position in September, 1916.

As soon as the organisation in the Ministry for the provision of all mechanical transport supplies had been set in motion, a general review of the position as a whole was made by the Director-General. The salient features apparent at the time were broadly as follows: Of

the new vehicles for the British Army about 30 per cent. were being obtained from America; the British Army's requirement for spares for maintenance was increasing rapidly week by week and was likely to continue to increase, and the reserve stock of spares was generally admitted to be on too small a scale to meet sudden emergency. The Russians had put forward a large programme of requirements, and were seeking sanction either to purchase in this country or abroad through the medium of British credit. All indications pointed to the fact that the resources of the motor industry in this country, as they existed at the time, were wholly inadequate to meet the prospective demands for mechanical transport. Since the outbreak of war the resources of many manufacturers had been wholly or partially diverted from mechanical transport work to the manufacture of aeroplane parts and shells, although the country was far from self-supporting even in regard to the mechanical transport requirements of the British Government.[1]

The requirements of both the British Army and the Russians were broadly divided into three sections—(*a*) motor cars, armoured cars, etc.; (*b*) heavy motor lorries of 3–5 ton type; (*c*) motor cycles. The requirements of 3-ton lorries as estimated in September, 1916, for the British forces were 200 a week for the Army up to December and an average of 45 a week for the Royal Flying Corps. The programme of requirements submitted by the Russian representatives called for approximately 4,500 3–5 ton chassis and 8,000 touring cars, and it was evident that equipment on an equal scale would be required for some considerable time to come.

(*b*) INDEFINITE NATURE OF THE DEMAND.

Throughout 1917 the Ministry was working on a very indefinite programme of complete vehicles for the British Army, and there was no programme at all for spare parts, the demands for which were intermittent and sometimes very large. In order to organise manufacturing capacity to the best advantage, it was essential to know in advance what numbers would be required for the establishment and the reserve, and to have a regular programme for providing spare parts.[2] The main obstacle to the formulation of such programmes was that the number of vehicles required varied entirely according to the nature of the operations to be undertaken and the *terrain* upon which they took place. Demands from the new theatres of war could not possibly be foreseen. Accordingly, when it was ultimately arranged that an estimate of weekly requirements should be provided beforehand, both the War Office and the Air Ministry were obliged to reserve a right to make urgent spot demands to meet unforeseen emergencies, and these were so considerable that they made the work of securing regular supplies extremely difficult.[3]

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[1] HIST. REC./H/1920/1.
[2] D.M.R.S. 430 J.
[3] D.M.T./1/S/54.

The weekly requirements for mechanical transport for 1918, as set out by the War Office and Air Ministry in December, 1917, were as follows[1] :—

Type.	*War Office.*	*Air Ministry.*
3-ton lorry chassis	350–400	41
F.W.D. lorries	20	—
Cars (open and closed)	60	43
Ford chassis, cars and vans	50	—
Holt tractors	11	—
Motor cycles, solo	220	38
side-car combinations	40	23

Mobile workshops, stores vans and armoured cars, caterpillar trailers, steam wagons, and steam tractors were demanded as required.

At this time Army authorities were urged to scrutinise their programme very closely with a view to avoiding any unnecessary demands. The financial position made it exceedingly desirable to terminate contracts for American vehicles which the Army Council wished to be continued,[2] and the American Board had refused to sanction allocation of dollars for renewal of contracts for mechanical transport vehicles from America in the absence of an authorised programme with definite rates of wastage.[3] A strong opinion existed that in many cases worn parts were replaced unnecessarily soon, and in view of the great shortage of material and labour it was most important that parts should not be replaced before they reached a state of wear definitely injurious to transport efficiency. It is, however, easy to understand that this suggestion would not have commended itself to the armies in the field. The efficiency of a supply column depended on its weakest member, and a breakdown in one unit in the field immobilised the whole column until the damage had been repaired. It was extremely difficult to estimate the rate of wastage. On the other hand, the spasmodic demand for large quantities of spare parts had a serious effect upon the manufacturing programme for complete vehicles.[4]

(c) War Office Programmes in 1918.

Throughout 1918 the requirements for motor lorries remained the subject of discussion between the Ministry and the War Office. At the beginning of June they were provisionally fixed at 270 per week, in addition to the 45 required for the Royal Air Force, but by 8 June they had been raised to 310 per week,[5] the shortage of horses having rendered it necessary to put units, which had hitherto been provided with horse transport, on to a mechanical transport basis.[6] Towards the end of July, 265 heavy lorries per week was given as a provisional figure, but

[1] D.M.R.S. 430 A.
[2] Letter from Mr. Churchill to Lord Derby, 12.1.18. (Printed) *Summary of Official Correspondence.*
[3] D.M.R.S. 430 A.
[4] See below, Chap. IV.
[5] (Printed) *Weekly Report*, Nos. 144 and 145, Part II, Table XI (1 and 6.6.18).
[6] M.C. 749.

at the date of the Armistice no definite arrangement had been made.[1] A detailed programme of requirements was furnished by the War Office at the beginning of June as follows:[2]—

Type of Vehicle.	*Requirement per week.*
F.W.D. chassis	20
Trailers for R.A.F.	60
Light lorry vans	49
Ford motor cars	10
Ford vans	35
Ford ambulances	5
Motor cars complete	50
Ambulance bodies fitted to chassis	11
Caterpillar tractors[3]	11
Motor cycle combinations	63
Motor cycle solos	235
Pedal bicycles	1,500

In July and August the programme underwent some slight changes, and from August onwards the following programme held good until the Armistice:—

Type of Vehicle.	*Requirement per week.*
Heavy lorries—	
War Office	265
Royal Air Force	45
F.W.D. chassis	25[4]
Trailers (Royal Air Force)	60
Light lorry vans (Royal Air Force)	50
Ford motor cars	20[5]
Ford vans	35[5]
Ford ambulances	6[5]
Motor cars complete—	
War Office	50
Royal Air Force	31 (per month)
Ambulance bodies	11
Caterpillar tractors	5[6]
Motor cycle combinations	63
Motor cycle solos—	
War Office	315
Royal Air Force	140 (per month)
Pedal bicycles	1,500

Large spot demands continued to be received throughout 1918.[7] In June it was stated that since the normal programme for the year had been put forward demands had been received for some hundreds of steam vehicles, trailers, bodies, and water-tanks. As there was no advance allocation of manufacturing capacity or material for these, sources of supply had to be obtained and assistance given in the supply

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[1] (Printed) *Weekly Reports, passim.*

[2] (Printed) *Weekly Report,* No. 144, Part II, Table XI (1.6.18).

[3] In addition to the definite weekly requirement, a contract was in force for 500 tractors for the Forage Committee, deliverable at the rate of about 20 per week.

[4] 20 from home, 5 from the United States.

[5] From these contracts allocation was made to the Royal Air Force by the War Office of 50 vans and 35 cars per month.

[6] Contracts in force for 500 tractors for Royal Air Force and Forage Committee.

[7] (Printed) *Weekly Report, passim.*

of material and labour.[1] For the week ending 1 June the spot demands received were for 41 trailers for mounting with generating sets for searchlights, 22 side-cars, 1 steam wagon, and 3 motor road rollers, while notice was given of a forthcoming urgent demand for 800 special trailers.[2] High-water mark appears to have been reached in the week ending 20 July, when spot demands were received for 100 35 horse-power steam tractors, 100 touring cars, 10 Crossley chassis specially fitted for wireless sets, 71 lorry bodies, 20 steam wagons, fitted with disinfectors, 24 side-cars, two 300-gallon water-tanks, and the conversion of 70 horizontal plane carriers to vertical type.[3]

Owing to this comparative indefiniteness of the programmes for land service vehicles, engine builders preferred contracts for aero-engines upon which they could obtain continuous output over a long period.[4]

Lack of statistical information as to establishment, stocks, and wastage of mechanical transport at first made it impossible to form an opinion as to the relative urgency of demands for mechanical transport in comparison with other requirements; and it was not until the summer of 1918 that the Ministry was fully informed upon these points.[5]

The question of wastage was very closely allied with that of repair, for which the Ministry of Munitions was not responsible in this case, although it undertook the repair of nearly every other store supplied. The War Department vehicles were repaired in France and at Camberwell and Grove Park, and the Royal Naval Air Service vehicles were repaired at the Wormwood Scrubbs Transport Depot.[6] In the spring of 1918 some new arrangements had to be made for the repair of motor lorries in England. The Association of British Motor and Allied Manufacturers, Ltd., had been in correspondence with the Ministry on this subject, and it was found that without detriment to the production of new vehicles, repair could be undertaken by the principal manufacturers to the extent of approximately 100 lorry chassis per month, and in about 2 months the output could be increased to 200 per month. In addition there were facilities for the repair of between 200 and 240 Ford vehicles monthly. This result was obtainable by the utilisation of resources available on account of extensions to works undertaken in connection with the Russian orders and not fully used.[7]

Subsequent offers of the Association to undertake repairs, subject to certain advances and the provision of 1,000 skilled men, were however, rejected by the War Office. A large central depot for the repair of vehicles was then in the course of preparation. Constructional work at Cippenham was begun in June, 1918. At the same time it was agreed that the surplus facilities of firms making new vehicles under Ministry orders should be employed upon repairs, even when

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[1] (Printed) *Weekly Report*, No. 144, VIII (1.6.18).
[2] *Ibid.*
[3] *Ibid.*, No. 151, VIII (20.7.18).
[4] M.C. 2138.
[5] W. 247.
[6] D.M.R.S. 430 N.
[7] D.M.R.S. 430 A.

the depot should have started work. This it did not do until after the Armistice; and in the meantime the continued accumulation of large numbers of unrepaired vehicles added considerably to the difficulties of maintaining supplies upon a satisfactory basis.[1]

IV. Development of Supply.

As has already been stated, the resources of the British motor industry were inadequate to meet the heavy demands for mechanical transport which were required by the British and Russian Armies in September, 1916. This applied particularly to lorries and cars of all descriptions, the British capacity for motor cycles being fully capable of meeting all demands, but the supplies of cars and lorries were inadequate for British requirements alone and left no surplus for Russia. The purchase of equipment abroad was discountenanced by the Treasury, therefore immediate steps were necessary to increase home production.

(*a*) STEPS TO EXTEND THE MANUFACTURE OF BRITISH TYPES.[2]

The position in regard to motor cars was exceptionally unfavourable since only a small number of the makers of the best types of British cars had been allowed to continue on that work, the others having been turned over to aeroplane or other work. An expansion of the output of these few firms could be and was later arranged, but not in anything like sufficient quantities to meet total requirements. The position, however, appeared to be different in regard to heavy motor lorries. Only a comparatively small number of the companies engaged in the trade before the war had been turned over to other work, and although expansion had taken place amongst those left, it had not by any means reached the limits of possibility. It seemed that considerably more use might be made by the larger firms of the resources of smaller firms for manufacturing parts, so as to allow of the larger manufacturers concentrating more freely on assembly work; further, as considerable supplies of a subsidy type of engine had been arranged for by the Mechanical Transport Department it appeared practicable to utilise this source of supply to overcome an apparent shortage of engines.

Steps were accordingly taken to get into touch with the makers of all types of heavy 3-ton lorries supplied to the British Army and Air Services, and to place before each the very urgent necessity of increasing production to the fullest possible extent, and the manner in which this might best be effected. They were, however, warned that it would not be possible for the Ministry to give any assistance in regard to labour; and that increased production must be obtained with the present

[1] The account of the Cippenham depot as a post-armistice measure falls outside the scope of this statement. Details of its history can be obtained from the *Report of the Joint Select Committee on Government Works at Cippenham*, 1919, Cd. 131.

[2] HIST. REC./H/1920/1.

nucleus of staff aided by further dilution. From each of these manufacturers information was obtained as to the help which would be required from sub-contractors, and whilst the main contractors were considering the practicability of the scheme, provisional arrangements were made with the more important sub-contractors.

The following table reflects the result of the negotiations which took place, showing in the first column the output of 3-ton lorries of British make per week at the time the negotiations took place, and in the following two columns the promised output per week after the scheme of increased production would become fully effective, divided into (*a*) probable output and (*b*) possible output. Three of the firms promised a very large increase in output but it was not thought wise to place absolute reliance upon this production.

	Output in chassis per week, September, 1916.	Proposed output in chassis per week.	
		(*a*) Probable.	(*b*) Possible.
Leylands	30	60	100
Albion	28	40	40
Associated Equipment Co...	27	60	100
Thornycroft	20	40	60
Dennis	12	25	25
Commercial Cars	12	20	25
Karrier	8	20	20
Maudslay	8	15	15
J. & E. Hall	5	10	10
Walker Bros.	2	2	5
	152	292	400

Provided the promises as set out above were fulfilled, a surplus would be available to meet Russian requirements; it was hoped that this surplus would begin to materialise about April, 1917, and continue to increase until September, 1917, when the maximum should be approached.

Practically all negotiations which took place with manufacturers and sub-contractors were conducted at conferences at the Ministry of Munitions, at which were represented the different branches connected with mechanical transport supply. At these conferences, questions affecting output, extension of buildings, plant and equipment, finance and prices were discussed. The fact that each section of the Department was represented expedited preliminary arrangements for increased output, for the manufacturers were able to proceed at once on the basis of the arrangements provisionally made at these meetings. Contractors were asked to state in writing their interpretation of the arrangements made, and this was compared with the minutes of the meeting and confirmed if correct. On the whole this system was found to work satisfactorily.

In order that questions of finance might be dealt with at these meetings, it was considered desirable that the Controlled Establishments Branch should delegate a limited authority to Mr. Palmer, of the Finance Section, to negotiate the amount of allowances in respect of new extensions which the manufacturers would be allowed to write off against profits before fixing their liability for excess profits duty. This question invariably proved a difficult one to settle, and was likely to cause delays in proceeding with extensions, inasmuch as business men were disinclined to lay out money on extensions before knowing how they would stand in regard to writings-off, and the proportion of profits derived from such extensions which they would be entitled to retain both under the Munitions of War Acts and Rules and the Finance Acts. It was thought that delays were more likely to occur if this question were left to be settled in the ordinary routine by the Controlled Establishments Branch. This innovation was open to criticism, as varying to some extent the usual practice, but it undoubtedly facilitated a settlement with the manufacturers in the great majority of cases, and as Mr. Palmer's powers were strictly limited as to the maximum allowance which he could grant, there was no danger of over-generous terms being granted in order to secure output. Any delays which did occur in this connection were due to manufacturers declining to proceed on the terms which Mr. Palmer was empowered to offer, and electing to settle the matter direct with the Controlled Establishments Branch.

The following definite arrangement in the case of a loan by the Ministry to one firm indicates the general lines of settlement in the majority of cases. The firm received a loan of £32,000 for extensions to their existing works, subject to verification of actual expenditure, the loan bearing interest at the rate of 1 per cent. above Bank rate, subject to a minimum of 5 per cent., and repayable to the Ministry within three years up to the extent of 60 per cent. of the amount loaned. The balance of 40 per cent. was a first charge on the excess profits of the firm, or, failing such profits, it was payable as a grant.[1]

In connection with most of the provisional arrangements made by the Department for extension to premises and additions to plant, a certificate was obtained :—

1. Through the manufacturer from his proposed contractors, that building labour was available to complete extensions.

2. From the manufacturer, that the labour which he had available would be adequate with dilution to fill the works when the extensions were complete.

In the case, however, of firms engaged on heavy stamping work, the second certificate could not be obtained, and further supplies of skilled labour, limited in amount, were required to work to its full capacity the additional plant arranged for.

The approximate total cost of the extensions and additional plant and tools arranged for was £1,000,000.[2]

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[1] HIST. REC./H/1920/2. [2] HIST. REC./H/1920/1.

An important concession affecting terms of running contracts was granted to all manufacturers supplying the heavy type of motor lorries, and also to some of the sub-contractors. It is believed that without this concession it would not have been possible to make progress at all, whilst there was a grave risk that manufacturers would gradually restrict output as time went on. Under the terms of the original running contracts with the War Office, manufacturers were entitled to only six weeks' notice of termination ; as, however, their commitments, including stock in hand, very much exceeded the equivalent output for six weeks, this condition of the contract was looked upon very unfavourably by manufacturers. This point of view was repeatedly put before the Supply Department by representatives from the chief firms, and it was finally agreed to offer as a concession to all alike a notice of six months in place of the six weeks' notice as previously provided for. In view of this concession, it was possible to obtain not only the generous co-operation of the firms interested, but also, in several cases, to negotiate a reduction in the price of motor lorries.[1]

It was, however, found in May, 1917, that the result of the long notice had been that certain manufacturers had obtained supplies of parts and materials for a long way ahead, while others had been starved, and it was suggested that it would be an advantage to the Government if the contracts were terminated, in order that the terms might be readjusted, and a shorter period of notice agreed. There seemed to be a danger that at the end of the war the market would be flooded with war-type vehicles, since the Ministry would be bound to take delivery for six months. It was therefore arranged in June that the agreed notice should be given. The Director of Mechanical Transport was of opinion that a shorter period would suffice if proper means were taken to ensure a supply of materials and parts to the contractors making the complete article. Contractors for materials and parts were liable, if a long contract was not placed with them by the makers, to divert their supplies or raise the price, but it had been found possible by a combination of persuasion and compulsion, and by working through the inspectorate, to maintain a fairly steady supply of parts and materials for the different makers. The position as to raw material had greatly altered since the six months' notice agreement had been made, and was becoming such that producers of raw material and parts could only supply from hand to mouth, and that if an order was given far ahead by any particular firm it could be fulfilled only at the expense of other firms. The principal reason for the long notice had therefore ceased to exist.

This step did not meet with the approval of the motor manufacturers, who were of opinion that it would be impossible to maintain the desired rate of output under the expansion scheme without a six months' contract, having regard to the fact that orders for material were placed more than six months ahead. The firms were therefore notified that they should continue to order materials and components to maintain maximum output month by month after the expiry of the six months,

[1] Hist. Rec./H/1920/1.

which fell upon 23 November, the Ministry undertaking to be responsible for any materials so ordered, if it should afterwards be found necessary to discontinue the supply. Shortly after the serving of the notice, manufacturers began to press for a decision as to what arrangements were to be made after November, in order that they might make arrangements for transfer to other work if necessary. At a meeting with the Association of Motor and Allied Manufacturers, Ltd., it was pointed out by the Director of Mechanical Transport that public opinion would be strongly opposed to the continuance of manufacture so long after the close of hostilities, if the war should soon cease. He suggested a plan whereby the Ministry should share the responsibility for material which might be left on the makers' hands, in so far as those materials could not be used by the manufacturer for the ordinary purposes of his trade. It was also suggested that firms should inform the Ministry from time to time as to the orders they placed for materials and sets of parts. Firms were asked to supply evidence indicating the quantity of necessary stocks for their respective outputs, and it was found that on an average the output represented by stocks amounted to 35½ weeks. Finally, an agreement was reached with the manufacturers in September, and the following break clause was inserted in all contracts:—

> "The Minister, in addition to his other powers hereunder, shall have the power to terminate the maximum output hereunder of complete vehicles at any time by giving eight weeks' notice in writing.
>
> In that event he will accept at the contract price, eight times the weekly average of complete vehicles delivered during the preceding four full working weeks. Such vehicles are to be deliverable to the Minister over a period of six months or within a shorter period at the option of the contractor and the Minister will be responsible for relieving the contractor of materials and parts of vehicles which may be in stock or in course of manufacture or on order (hereinafter referred to as stocks) at the date of the giving of the said notice on the following conditions:—
>
> (*a*) The contractor may, subject to the paragraph next succeeding hereto, carry such an amount in cost value of stocks as shall not exceed in total the cost value of materials and parts required for an output of seven full working months calculated upon the average monthly output for the previous three full working months.
>
> In respect of any specific material or part, the Minister shall not be responsible for more than 25 per cent. excess (hereinafter called the initial excess) above that required for the agreed period of output, *i.e.*, seven full months except where an excess larger than 25 per cent. (hereinafter called the sanctioned excess) shall have arisen with the express sanction in writing of the Minister, provided that where such initial excess arises of any specific material or part a corresponding reduction shall be made by the contractor in the amount to be claimed in respect of other material or part of the said stocks, so as to secure that the total cost value of stocks shall

not at any time exceed the amount stated in the paragraph last preceding and provided that where any sanctioned excess arises the Minister shall assume responsibility for relieving the contractor of the said sanctioned excess.

(*b*) The Minister shall assume responsibility for stocks within the limits of sub-clause (*a*) hereof on the date of the giving of notice other than the materials required for the purpose of building the vehicles to be delivered under the first paragraph hereof, and will pay for the same the cost incurred by the contractor calculated on the following basis :—

(1) The cost of material.

(2) The cost of the actual productive labour employed on such material in course of manufacture.

(3) Such establishment charges as the Minister may consider to be reasonable and properly applicable.

(4) An allowance of $1\frac{1}{2}$ per cent. upon the total (to represent interest on capital employed).

Provided that the Minister shall pay the contractor not less than 80 per cent. of the amount so arrived at within one month after the date of expiration of the notice of eight weeks and the balance within six months.

And provided that for the purpose of section 3 of sub-clause (*b*) hereof, regard shall be had to the actual rate of establishment charges experienced by the contractor during the six months preceding the date of giving of notice.

And provided that failing agreement within one month in respect of section 3 of sub-clause (*b*) hereof, payment of 80 per cent. of the amount claimed by the contractor on the certificate of the contractor's auditors shall be paid to the contractor and the necessary adjustments (if any) shall be made on subsequent agreement.

And provided that upon receipt of the said notice the contractor shall take stock at his factory, such stocktaking to be subject to verification by the Ministry within a reasonable period.

(*c*) The contractor shall re-purchase from the Minister at the price provided for in sub-clause (*b*) for twelve months after the date of the giving of notice, and thereafter at current market prices, such parts and materials as he can use. It is the spirit of this clause that in order to assist the Government, the contractor shall re-purchase as much material and parts as possible. He shall refrain from purchasing at lower prices in other quarters, material or parts identical with or otherwise suitable for the same purpose as that in stock, and available for re-purchase.

(*d*) The Minister shall have the option of calling on the contractors to manufacture such stocks as aforesaid into complete vehicles and for this purpose the contractor shall duly make and sell to the Minister such complete vehicles at the contract price per vehicle.

Provided that such option is exercised by the Minister within three and a half months of the date of the giving of notice under paragraph 1 hereof.

And provided that the exercise of this option shall not prejudice the payment of the 80 per cent. mentioned in the first proviso to sub-clause (*b*) above.

And provided that the contractor shall not be compelled to deliver these vehicles at a rate exceeding 50 per cent. of his output at the date of the giving of notice of termination."

In many cases it was possible to invite tenders for supply, and this method was adopted when the running contracts for lorry bodies placed by the War Office expired, and renewals were necessary. These contracts had been placed without recourse to tender and the adoption of the latter method of obtaining supply resulted in a considerable reduction in price, although when shortage of material and labour eventually became severe the prices gradually rose again to a higher level than before. In cases of urgency applying to particular demands it occasionally became necessary to accept tenders wherein the delivery offered was the quickest, irrespective of price. A good many of the demands were of a repeat nature, for which supply arrangements were simple. Others entailed considerable technical knowledge and a search for suitable sources of supply. In this connection the assistance of the Inspection Department was frequently invoked.

The provision of mechanical transport supplies was rendered difficult throughout the war by the low priority granted for the manufacture of motor vehicles. In March, 1917, aircraft manufacture and repair of guns, tanks, and railway transport all took precedence over mechanical transport as to the supply of labour and material.[1] This arrangement did not, however, preclude the granting of higher priority in cases where a firm holding a contract for mechanical transport was able to prove inability to obtain specific material in connection with it, under the ordinary classification (P.4), provided more important work was not thereby affected.[2] About May, 1917, the position in relation to the supply of spare parts was so unsatisfactory that as the result of a conference at the War Office it was decided that for the next few months mechanical transport should be placed on an equality with tanks and railway transport.[3]

The low priority accorded to mechanical transport caused particular difficulty with regard to labour, since employees of motor vehicle makers took service with firms engaged on Government work of higher priority, under the impression that such firms were in a better position to obtain protection for their employees from military service.[4] The difficulty in obtaining labour increased as the war progressed and the motor works were seriously disorganised from time to time on account of the withdrawal of labour, but the firms faced the position so resolutely as to reduce to a minimum the resultant decline in output.[5]

[1] D.M.T./1/B/6.
[2] Hist. Rec./H/1920/3.
[3] D.M.T./1/B/6.
[4] (Printed) *Weekly Report*, No. 143, VIII (25.5.18).
[5] Hist. Rec./H/1920/3.

(b) The Supply of American Types.

Contracts for American vehicles were at first arranged through the agents of the various American firms in this country; but arrangements were made for keeping the purchasing agents (Messrs. Morgan) informed of these orders. In December, 1917, this procedure was modified by a decision that all American orders should be placed by the Inter-Allied Council in America through the American Branch of the Ministry.

When the Ministry of Munitions took over the supply of mechanical transport the supplies from America formed an important item in meeting the total requirements. Heavy lorries were being imported at the rate of 70 a week. Twenty four-wheeled drives and eleven caterpillar tractors weekly were obtained on running contracts. Since the beginning of the war the military authorities had been urged to terminate these contracts at the earliest possible moment, but the supply situation had not warranted this course at the end of 1916. No four-wheel drive lorries or caterpillar tractors were at that time forthcoming from British sources and it was calculated that if notice was given for terminating the heavy lorry contracts there would be a period of about four months during which the British Army would be short, before British factories could supply the deficit.[1] At the beginning of 1918 the shipping situation made it imperative to reduce the American orders as far as possible, and in February it was arranged that contracts for lorry chassis, with the exception of four-wheeled drives, should be cancelled provided the American contractors would supply the necessary spare parts for the lorries already in use.[2] By May, 1918, the contracts for four-wheeled drives had been reduced to five a week as from 1 July and those for Holt tractors to five a week as from the same date.[3]

The department of the Ministry, formed in May, 1916, to supply mechanical transport for the guns ordered in excess of the War Office programme, took steps immediately to develop manufacture in this country of two types required, *i.e.*, the four-wheeled drive lorry and the caterpillar type tractor. American made vehicles of each of these types were borrowed from the War Office and examined by the technical assistants and engineers of the department, the general design being modified to conform as far as possible to British manufacturing practice. In the case of the four-wheel drive several firms were entrusted with the production of the units, such as front and rear axle, gear box, clutch and engine, each firm concentrating on a particular unit. The work of assembling the components into parts was placed in the hands of another company, but, owing to unforeseen difficulties in manufacture and shortage of material and labour, output did not commence for several months after the expected date, and the total number of vehicles produced under the scheme was only 509, production continuing until after the Armistice. Very few of these four-wheel drives were despatched to Russia, their intended destination.[4]

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[1] Hist. Rec./R/1920/1.
[2] D.M.R.S. 430 A.
[3] (Printed) *Weekly Report*, No. 143, VIII (25.5.18).
[4] Hist. Rec./H/1920/2.

The building of the modified Holt caterpillar tractor was, with the exception of the engine, carried out by Messrs. Ruston, Proctor & Company, Lincoln, the engine being a four-cylinder unit supplied by Messrs. Perkins (Engineers), Limited. The manufacture of an entirely new design of caterpillar tractor was undertaken by Messrs. Clayton & Shuttleworth, Lincoln, with the exception of the engine, which was supplied by the National Gas Engine Company, Ashton-under-Lyne. The War Office were promised that 600 of these tractors would be completed by the end of December, 1916, but owing to an over-estimate of the capabilities of the two firms concerned, and to difficulties in obtaining material, actual deliveries did not commence until the end of February, 1917, and then only at the rate of eight per week, though this figure was afterwards improved upon. Only a small fraction of the tractors produced were actually shipped to Russia, the balance being taken over by the War Office.

The Traction Branch of the Mechanical Warfare Department was established on 26 August, 1918, with Sir Percival Perry as Director, to undertake the production of the light gun tractors on caterpillar tracks, as demanded by the Army Council in August. The programme before this section was to procure 20,000 tractors, 10,000 to be delivered by April, 1919, purchasing the necessary power units and transmissions and other supplies not procurable in Great Britain, from America, and obtaining hulls and all other supplies in Great Britain. For this purpose tractor factories were acquired at Manchester for receiving the supplies and assembling the tractors. These factories were the property of the Ministry and under the administration of the Agricultural Machinery Department. Major Norman E. Holden was transferred from the Mechanical Warfare (Overseas and Allies) Department to take charge of the American office organisation, but he did not reach the United States until 28 October, 1918. Contracts were placed and deliveries had begun before the Armistice, but on 20 November, 1918, it was decided not to proceed with these tractors.[1]

(c) Aeroplane Trailers.

Towards the end of 1917 some difficulty was experienced in obtaining aeroplane trailers in sufficient quantities. This was due to the restricted output of axles and iron work, the source of supply being limited to two firms, who were already overcrowded with other Government work. Their inability to supply these components to the body builders restricted output.[2] The sources of supply were therefore extended, but in the summer of 1918 output was again limited, this time by a shortage of wheels.[3] The production of aeroplane trailers remained poor until November, when output was increased as the result of a further extension of the sources of supply for components.[4]

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[1] Hist. Rec./R/1940/39; D.M.T./5/R/8.
[2] D.M.R.S. 430 N.
[3] (Printed) *Weekly Report*, No 145, VIII (8.6.18).
[4] (Printed) *Weekly Report*, *passim*.

V. Control of Manufacture and Sale.

On 3 November, 1916, an Order[1] was published by the Minister the effect of which was to restrict, as from 15 November, any work other than Government work, consisting in the manufacture, assembly or erection of any new or unused motor internal combustion engine, motor car chassis, etc. The object of the notice was, in the first place, to stop non-essential work such as the building of pleasure cars, and thereby to release labour trained in the motor industry for more essential Government work. The Order was also intended to embrace within its operation the assembly of American or other imported types of cars, partly to release labour, but also with the object of restricting importation. In connection with the administration of the Order a system of permits was introduced so that essential work which could not be classed as Government work might not be stopped altogether, and a working arrangement was arrived at with the Priority Department, whereby such permits could only be granted after consultation and agreement between the two departments.

This Order was also utilised to give the Mechanical Transport Department the control of the sale of all except second-hand vehicles, and permits to purchase were only granted after a most careful scrutiny of the purposes for which the cars were to be used. The granting of permits was subsequently made much more stringent in view of the requirements of the Petrol Control Committee, chiefly in order that no purchases of motor cars, etc., should be made in cases where a new or increased petrol licence was involved, and was not likely to be granted by the Petrol Control Committee. Eventually permits to purchase motor cars, motor vehicles, or motor cycles were only granted in cases of real and urgent national importance, and when the vehicles were directly or indirectly necessary for the successful prosecution of the war. When it was clearly shown that an application came under this heading, an undertaking was required, before the permit was issued, that the motor vehicle should be used exclusively for the purpose or purposes for which the permit was issued, and that the vehicle purchased under the permit should not be disposed of during the war without the consent of the Department. In order to make quite certain that the Order would give the Department control of the sale of vehicles already imported, which was disputed by one firm, the Order was altered (in January, 1917), at the request of the Department,[2] so that the control was absolute over vehicles already in the country, while further permits to import were only granted on the recommendation of the Department.

In connection with the issue of permits a census was made of all motor vehicles (both of the commercial and the private type) in manufacturers' or agents' possession, or under construction in the country outside those required for Government purposes. This census disclosed that there was a very considerable stock of imported vehicles, and also a fair number of vehicles under construction by British firms, and therefore importation of further vehicles for other than Government

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[1] Appendix (*a*).

[2] Appendix (*b*).

purposes was stopped with the exception of those propelled by electricity of which there was practically no stock and no manufacture in this country. This prohibition undoubtedly acted somewhat unfairly in favour of those firms who had large stocks as against those who had none, and also against those firms who had placed large orders in America for vehicles designed specially for use in this country; but in the national interests this could not be avoided. A scheme of permits was, however, instituted to enable importers to obtain sufficient spare parts at a monthly rate, so that imported vehicles engaged upon work of national importance in this country could be maintained in service.

VI. Liquidation of Contracts.

The notice to terminate under the break clause was sent out on 12 November, 1918, and subsequently arrangements were made under which contractors were to deliver to the Ministry a fixed number of complete vehicles in all cases less than the Ministry was actually liable for under the break clauses of the contracts. In some cases monetary compensation was given to cover non-standard parts which contractors would have to scrap.

The numbers of vehicles which the Ministry agreed to take during the period of notice were still further reduced (under the option which contractors were given to deliver elsewhere than to the Ministry) when it was found that the War Office did not need them and that they would therefore be surplus to Government requirements.

Delivery of vehicles outstanding on these terminated contracts ceased early in 1919, and about 1,500 lorries and 1,000 cars, ambulances and light tenders were delivered to the Ministry after notice of cancellation of the contracts was given.

Except in the case of one firm who were given compensation to the amount of £139,000 for cancellation at the time of the Armistice of delivery of 1,050 lorries and £130,000 for cancellation at a later stage of delivery of 680 lorries, the amount paid to mechanical transport vehicle manufacturers, by way of compensation in connection with the cancellation of contracts with the Ministry, was small.

The total value of outstanding deliveries on mechanical transport contracts at the date of the Armistice was about £8,000,000, covering approximately 900 contracts. About 700 of these, on which the outstanding deliveries were valued at approximately £1,000,000, were allowed to be completed. The remaining 200 contracts, on which the outstanding deliveries were valued at approximately £7,000,000, were liquidated for a total cash payment, as compensation, of approximately £370,000.

Of the £8,000,000 outstanding on the mechanical transport contracts at the Armistice, about £3,500,000 was liquidated by bringing the break clauses into effect at the time of the Armistice, leaving a commitment of £4,500,000. This was subsequently reduced to about £3,000,000 by contractors delivering elsewhere under the options given them and by compensation being made to the total amount of £370,000 as above mentioned.

CHAPTER IV.

SUPPLY OF COMPONENTS AND MATERIALS.

I. Spare Parts.

(*a*) Organisation for the Supply of Spares.

The provision of spare parts, tyres, and miscellaneous items of supply was at the beginning of the war vested in the Mechanical Transport Inspection Branch of the Army Service Corps. The headquarters of this branch were at Aldershot, but were removed early in 1915 to Short's Gardens, London. Since, after the outbreak of war, this branch no longer dealt with the actual inspection of vehicles, its title was altered in October, 1915, to Home Mechanical Transport Depot, A.S.C. This depot grew very rapidly as the introduction of hundreds of new vehicles into the service automatically resulted in increasing demands for spare parts and accessories, and eventually the formation of a number of sub-depots became necessary. The provision of these maintenance supplies was at first in the hands of the Chief of the Inspection Branch, with a relatively small staff. The need for extension soon became evident, and a number of well-known automobile engineers joined the service. The Chief Inspector had power to purchase spare parts and tyres to any extent required, but his direct purchase of accessories and miscellaneous items of supply was limited to an amount not exceeding £500 for individual orders, while officers in charge of stores could purchase up to the value of £100.[1] Accessories and miscellaneous supplies exceeding this limit of expenditure in any one case were obtained on the detailed demands of the depot, by the Contracts Branch of the War Office by open tender or direct contract. The depot purchased and provided spares on what was called a 3 per cent. schedule for each make of vehicle introduced into the service. Stocks of other articles, including tyres, were maintained on a basis of quantities demanded over a fixed period. Demands from overseas and from units in this country were met, as far as possible, from these stocks. Ford spares were imported by the firm under " blanket orders " and held by them to meet demands from the Home Mechanical Transport Depot. The inspection of spares, tyres, and miscellaneous articles was undertaken by the Home Mechanical Transport Depot after delivery.

When the Ministry of Munitions became responsible for the supply of mechanical transport a certain number of officers and men of the Army Service Corps, who had been employed at the Home Mechanical Transport Depot in the provision of spares, were transferred to the Ministry and formed a separate section (D.M.T. (S.)) of the Directorate

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[1] D.M.T./1/T/8.

of Mechanical Transport. Their powers of purchase were transferred with them, so that the only spares and accessories dealt with in the normal way by the Contracts Section of the Ministry of Munitions, were those for which the Director of Army Contracts had formerly been responsible, *i.e.*, those which the Home Mechanical Transport Depot was unable to supply. All demands for spares and accessories passed in the first place to the O.C. Home Mechanical Transport Depot, who passed to the Ministry any with which he was unable to deal.[1] When the supply of vehicles for the Admiralty was taken over by the Ministry a similar arrangement was made for providing spares,[2] but in practice, since Admiralty vehicles in most cases differed from those of the War Department, it was found more expeditious to forward demands directly to the Ministry for action by the contracts section (P.M. 4).[3]

In the middle of 1917 the procedure in connection with demands received by D.M.T. (S.) for spares was that the section placed all orders directly with the firms concerned without reference to the contracts section. Each sub-section had its buyers to whom was allocated the work of instituting enquiries and placing orders. Orders were placed, as far as possible, in accordance with fixed price lists. The power of D.M.T. (S.) for placing orders was theoretically limited to £500 until October, 1917, when it was agreed that a representative of the Contracts Department should assist the head of Section D.M.T. (S.) in negotiating purchases of spare parts.[4] Slight modifications in procedure were made in the case of spares required by the Crown Agents to meet colonial requirements. These spares had to be suited to vehicles which had in many cases been in use in the colonies for some years, and the necessary technical information was available only in the offices of the Crown Agents. It was therefore agreed that they should conduct preliminary negotiations with the firms, in order to determine exactly what was required before actual orders were placed by the Ministry.[5]

(*b*) STORAGE.

The methods for maintaining and storing the necessary stocks of spares were still in course of settlement at the time of the transfer of responsibility to the Ministry. A two months' reserve was aimed at, but had not been attained. The War Office had considered the two alternative schemes of providing a big central store or making the manufacturers carry the necessary stocks of spares themselves. In view of the enormous difficulties involved in the provision of a big central store, the second alternative had been adopted, but the scheme had not been fully worked out by September, 1916,[6] except that a schedule based on previous demands had been issued to about a dozen lorry makers.

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[1] D.M.T./1/T/8.
[2] D.M.R.S. 430 A.
[3] P.M./Gen./790.
[4] D.M.R.S. 430 B.
[5] W. 247.
[6] HIST. REC./R/1920/8.

The Ministry extended the scheme to additional lorry manufacturers and also to car and motor cycle makers. Assistance was rendered to certain firms to enable them to provide suitable stores to carry the stock, and it was agreed that where these extensions would be of no use to the firm after the war, the whole cost would be borne by the Ministry on an agreed basis, but that if they would be of use after the war the expenditure should be subject to conditions whereby the firms met the cost. Many firms were, however, able to set aside part of their existing works for the storage of spare parts. The Home Mechanical Transport Depot was responsible for preparing the original schedules of the stock required to be held by each manufacturer. This depot also placed demands direct on the makers' stores for items required from this stock for Army purposes and notified the Ministry of the withdrawals. Fresh orders were then placed with the firms for items to replace those withdrawn. The Home Mechanical Transport Depot also advised the Ministry from time to time of modifications required in the original schedules. The inspecting officers of the Mechanical Transport Inspection Department of the Ministry were responsible for the inspection of all items before they were placed in stock at makers, and the Home Mechanical Transport Depot had representatives stationed at the works of some of the firms who carried the largest stocks in order to check additions and withdrawals and to keep the depot fully advised in regard to the position of the stock generally. A fortnightly return was also rendered to the depot by each manufacturer concerned showing the state of the stock, in addition to which the manufacturers were required to take stock quarterly. The preparation of these returns threw a considerable burden of clerical work upon the firms, and owing to representations made to the Ministry by the Central Council of Associations of Controlled Firms[1] arrangements were made to abolish the fortnightly return. This had become possible early in 1918 owing to the development of a new system of stock at makers' works which was brought into force at about this time. Under this scheme, each manufacturer was informed as to the maximum and minimum quantity of each particular item to be stocked. This gave him limits within which to work, stocks being built up at the works as soon as they were reduced below the minimum but no manufacture for stock being made when the maximum figure was reached.[2] This system proved to be very satisfactory in practice and was continued for the remaining period of the war.

(c) The Production of Spares.

The term "spare" as used by the War Office covered accessories such as lamps, generators, and tyres and all stores required for the maintenance of mechanical transport vehicles.[3] Difficulty in the provision of spares was experienced from the beginning of the war, but at the beginning of 1917 matters reached an acute stage. The main factors contributing to this were the turnover of works or parts

[1] 92/6285. [2] D.M.R.S. 430 B. [3] D.M.T./1/S/54.

of works to the manufacture of shell, aeroplanes, and tanks, the shortage of material and labour, and the low priority accorded to mechanical transport. Just at the time when these difficulties became marked, the opening up of new theatres of war led to fresh demands for transport, while the advance in the stage of wear of the vehicles which had accumulated in Army service resulted in increasing demands for spares. In March, 1917, the Commander-in-Chief in France represented the urgent necessity for the fulfilment of outstanding demands for spare parts, particularly for Daimler, Sunbeam, and Rolls-Royce cars.[1] A detailed description of the difficulties encountered in obtaining such spare parts at the time and the special steps necessary to overcome them affords a good illustration of the involved situation in regard to the supply of spares generally at this period.

The Daimler Company were engaged on tank and aeroplane work, both of which took precedence of mechanical transport orders. By careful investigation it was found that the tank work was less urgent than had been represented, and it was possible to arrange for the firm to allocate more men to the manufacture of spare parts for cars, with the result that the shortage of spares was to some extent met. The Sunbeam factory had, with the consent of the War Office, been turned over to the manufacture of aero-engines for the Admiralty, and arrangements had been made for the Rover Company to manufacture the Sunbeam car. A large number of Sunbeam parts were in urgent demand before the Rover factory could be got going, and arrangements had, therefore, been made with the Admiralty in December, 1916, whereby ten men at the Sunbeam works were allocated to the manufacture of these parts. Owing, however, to the urgent need for Sunbeam parts in the spring of 1917, special representations were made to the Admiralty, and the number of men employed on spares was increased in April to fifty. The Rolls-Royce firm was also heavily committed to aero-engine work, and though they obtained the assistance of the Midland Railway Company to help them in the manufacture of spares, the output did not meet the urgent requirements of the Army in France.

At the end of April, 1917, a further protest was received from the Quartermaster-General regarding the delay in the provision of spare parts, which he stated had become a serious matter, particularly in view of the fact that a proposal had been made to send out more lorries in substitution for horses.[2] The key to the whole situation was the supply of raw material, and the Ministry took the view that it was for the War Office to state whether or not the provision of spare parts was of equal importance with aeroplanes, gun manufacture and repair, tanks, and railway transport, as the Ministry was working on the assumption that the latter were of prior importance. The War Office intimated at the end of April that for the next few months the supply of spares for mechanical transport was of primary importance, and steps were taken by the Ministry to settle the question of priority, with the result that mechanical transport was placed on a level with tanks and railway

[1] D.M.T./1/S/54. [2] *Ibid.*

transport. This step was of some assistance, but the demands for spares increased so rapidly that delay still occurred in meeting them, and towards the end of July, 1917, further complaints were made by the Commander-in-Chief as to the inadequate supplies. In reviewing the situation at this stage it was found that the stock of spare parts was relatively greater in proportion to the number of vehicles than it was a year previously, in spite of concurrent efforts to increase the production of complete vehicles. In arranging for supply of spare parts the Ministry was greatly handicapped by the indefiniteness of the programme for complete vehicles[1] and a lack of information as to requirements for spares, the demands for which reached the Ministry spasmodically and often included parts such as radiators, cylinders, connecting rods, etc., which were hardly ever known to fail under ordinary circumstances.[2] At that time between 40 and 50 per cent. of the spare parts demanded had been available for supply from the stock at makers, but with regard to the balance it took from one to three months or even more to supply items required, the time varying according to the description of the article and according as it was obtained in England or America. Great and increasing difficulty was being experienced in meeting simultaneous demands for spares and complete vehicles. Motor works were designed to make a finished article with the comparatively small proportion of spares required in peace time, and the machinery was balanced accordingly. War requirements included large demands for particular parts, which meant that new machinery must be installed specially and devoted to those parts or else that output of complete vehicles must be reduced and some machinery left idle. Thus, apart from the fact that the War Office was demanding increased numbers of complete vehicles, the problem of spares supply could not be solved by concentrating firms on spares because the personnel and plant of the factories were not adapted for this. The difficulties of the situation were enhanced by the increasing demands of the new aircraft programme on material and labour of the same class as that employed on mechanical transport. The reduced tonnage at that time available for shipments from America further added to the difficulty of meeting requirements for mechanical transport.

The attention of the War Office was drawn to these difficulties in November, 1917, and it was pointed out that in view of the extreme importance attached by the Government to aeronautical supplies, it had become necessary that demands for mechanical transport and spares should be strictly limited, and the War Office was asked to use every effort to reduce demands for spare parts. It was suggested that the standard of efficiency for vehicles in France, which had been reduced in September, 1916, might be still further reduced without loss of transport efficiency.[3] The suggestion that a higher priority should be granted for spare parts than for complete vehicles appeared to be unworkable except in such cases as accessories and parts manufactured by small firms as their sole output. In the case of spare parts ordered in the

[1] *See* above Chap. III.
[2] D.M.T./1/S/54.
[3] *Ibid.*

manufacture of complete vehicles, these parts were usually put through the shops in batches which amalgamated the requirements for complete vehicles and spares, so that higher priority for parts only would have been of no appreciable benefit. Offering a higher price for spares provided no solution of the difficulty, the primary causes of which were shortage of material, machine capacity, and labour. Throughout 1918 the shortage of spares continued. In June stocks were in many instances insufficient to meet immediate requirements, and in general supply was in the neighbourhood of 60 per cent. of requirements,[1] which were specially large at that time owing to heavy and unforeseen demands by the American Army.[2] In July the Army Council pressed for higher priority for mechanical transport, but all that could be done at the time was to give motor vehicles equal priority with railway materials. It was at the same time pointed out to the Army Council that a reduction in their demands for complete lorries from 270 to 180 per week would set free capacity for the provision of spares and meeting outstanding demands, while a further reduction to 160 would liberate capacity urgently required for even more important work.[3]

Towards the end of the war shortage of shipping tonnage made the provision of spares for American vehicles a matter of great difficulty. Though American contracts had been reduced in the spring of 1918, the requirements of spare parts for the vehicles already in service were very large and reliance was still placed on American firms for these parts. The situation was gradually met as mentioned above, by the preparation by the Technical Section of working drawings of the American-made parts, making it possible to place orders for such parts in England.

The supply of spares remained below requirements until the end of the war, but it is worthy of note that in August, 1918, when many tons of spare parts were destroyed by intense bombardment at a mechanical transport base in France,[4] the Ministry was able to arrange for complete replacement of these spare parts within a few weeks. At the time of the Armistice, however, a portion of the fleet was unmobilised for want of spares.[5]

Some idea can be gathered of the extent to which spare parts were stocked by manufacturers from the fact that in July, 1918, there was roughly three million pounds worth in stock at over thirty manufacturers' works,[6] but since it was impossible at any time for the War Office to forecast accurately the actual parts required, a high percentage of the parts stocked lay redundant for months at a time.

Towards the end of 1916 the Ministry made it incumbent upon manufacturers to obtain permits before they could supply spare parts in any other direction than to the Government. The applications for these permits were passed by the Priority Department of the Ministry to the Mechanical Transport Department, which signified its consent to

[1] (Printed) *Weekly Report*, No. 147, VIII (22.6.18).
[2] *Ibid.*, No. 148, VIII (29.6.18.)
[3] D.M.R.S. 600 G.
[4] *Ibid.*
[5] M.C. 749.
[6] *Ibid.*

the issue of the permit or otherwise. In order to avoid delays inherent in this procedure it was subsequently arranged, in September, 1917, that all manufacturers of mechanically propelled road vehicles should be circularised and advised of a Ministry permit number and priority classification, under which they could supply spare parts or execute repairs, provided the total value (including the value of labour as well as material) did not, at any one time for any one vehicle, exceed £20 in the case of lorries, £10 in the case of motor vans, cars, and cycles, and £25 in the case of steam vehicles, and subject to a return being rendered monthly of all orders executed under this authorisation. These returns were subsequently found to be unnecessary, but manufacturers were held responsible for maintaining registers of the orders, which had to be available for inspection by the inspectors of the Priority Department or of the Mechanical Transport Department.

In the case of lorries and steam vehicles, the supply of spare parts or the execution of repairs under this procedure was applicable to any of the manufacturers' own make of vehicles in use in this country. In the case of motor vans, cars, and cycles, the method was applied only to certain classes of vehicles, notably those employed by medical men or naval or military officers in the pursuit of their professional duties, commercial vehicles or those plying for hire and others, such as motor fire-engines, engaged upon certain essential services. A written declaration was required from the user to the effect that his car fell within one of these classes. Moreover, no order in pursuance of this authority could be fulfilled by a manufacturer if it would directly or indirectly interfere with or delay the progress of any work or the execution of any order which was covered by Class "A" priority.

This system very materially reduced the number of applications for permits for spare parts and repairs to motor vehicles, and, as far as such applications were received, the arrangement whereby the Mechanical Transport Department was consulted before the permits were issued effectually prevented spare parts being released which were required or likely to be required to meet Government needs.

The release of Ford parts was dealt with in a special manner, inasmuch as all such parts were at the time imported under a "blanket" contract with the Government, which only allowed a very small margin for supply to private owners of Ford vehicles. Therefore it was arranged for the London manager of the Ford Company to bring to the notice of the Director of Mechanical Transport once a fortnight all applications received by the Ford Company in this country for Ford parts from other than Government sources. The Director of Mechanical Transport then signified which applications could be met by the Ford Company, always provided that Government requirements were not in any way affected thereby. This arrangement was subsequently superseded by one under which the inspecting officers of the Mechanical Transport Department were given authority to sanction the release of Ford parts.[1]

[1] D.M.T./1/S/54.

Shortly after the Ministry of Munitions assumed responsibility for the supply of mechanical transport it was suggested by the Contracts Department that much expense might be saved if the Ministry bought in bulk certain accessories required by the vehicle builders. General stores of a similar nature, for replacements, were already obtained by the Department in the open market. Investigation of the price lists showed that in many instances the prices asked by the makers for certain accessories such as radiators, steel road wheels, magnetos, steering wheels, ball bearings, and carburetters were excessive. The Director of Mechanical Transport, though agreeing in principle, pointed out that such an arrangement would not be found to work easily, because, even though the articles might be standard they would probably require adjustment by the maker of the vehicle, and as regarded stocks, the Ministry would have to provide storage. An alternative seemed to be to come to some arrangement with the vehicle makers to charge the price to be paid for the accessory plus a small percentage for handling and storage—the onus then being with the firm as regards the articles being correct and suitable for his vehicle.[1]

In the summer of 1917 each manufacturer included with the vehicles supplied certain equipment which varied very considerably, in some cases being very full and containing a considerable number of spare parts, and in others being very meagre. Accessories were provided in some cases by the makers and in other cases by the Department, after the vehicle had been accepted. Almost every make of vehicle required some special tool to enable various parts to be adjusted while on the road. Scales of equipment had recently been drawn up by the Army authorities showing (*a*) the stores which accompany every vehicle sent overseas; (*b*) the scale of equipment of motor lorries with general equipment, standard tools, special tools according to the make of vehicle, and spares; (*c*) similar scales for motor cars, ambulances, and vans; and (*d*) special tools applicable to each make of machine. It was considered that if this scheduled equipment were provided under contract with the vehicles by manufacturers, prior to delivery at Kempton Park, the work involved in drawing various articles from different stores would be eliminated and the parts for each vehicle would be standardised. An alternative method to which consideration was given, in order to avoid the adjustment of arrangements with makers which would be involved under the plan, was for the Department to order in bulk, direct from the trade, the items which were ordinary commercial articles and common to all vehicles. These could be held at Kempton Park Depot, to enable each vehicle to be equipped there either on arrival or issue. This system would have the advantage of economy, and would ensure uniformity in tools, etc. It would also probably mean quicker delivery, as priority would be higher on departmental orders, and the departmental "speeding up" system could be brought into force, and it would overcome the trouble of having vehicles delivered deficient in some items owing to the inability of the vehicle makers to obtain supplies. Many items of general equipment

[1] D.M.T./1/P/1.

were already held in bulk at Kempton Park for the equipment of each vehicle, while others were supplied and fitted by the makers. All tools special to each vehicle and spares, with the exception of bolts and nuts, would still have to be supplied by the vehicle maker; but as there was a number of bolts and nuts common to all types of vehicle, there seemed to be no reason why those should not be supplied in bulk to Kempton Park, and placed on each vehicle on arrival there.[1]

II. Standardisation of Components.

Though the various types of subsidised lorry were made to a standard specification, considerable variety existed in details of their construction. The production of a lorry of one standard design might have solved many problems with regard to spares and accessories, and a scheme for the production of such a type was begun by the Director of Munitions Mechanical Transport. The scheme was, however, superseded by the arrangement, of which details have already been given, whereby the output of existing types was increased.[2] Special attention was, however, paid to the standardisation of accessories. Lamps, generators jacks, and tyre pumps were among the accessories so dealt with. The standardisation of sparking plugs was an early and notable achievement and eliminated the necessity which had previously existed for ordering some 100 different makes. The necessity had arisen on account of a failure in the supplies of porcelain in the spring of 1915, entailing the use of any available type of plug.[3] The standard plugs were introduced early in 1917, and included two types, one for lorries and cars, and the other, a waterproof one, for motor cycles. When the firms manufacturing these plugs had sufficiently worked up their output, all the mechanical transport vehicle makers were required to fit such plugs to their vehicles as soon as their stocks of proprietary plugs were exhausted.[4]

Two components of mechanical transport, viz., tyres and ball bearings, offered peculiar problems in supply, and call for more detailed treatment.

III. Ball Bearings.[5]

In the early days of the war arrangements were made by the War Department for a specified number of sets of ball bearings to be provided to the contractors for vehicles by the established British manufacturers. The main source of supply was the Hoffmann Manufacturing Company, the leading firm in the ball bearing industry. Little difficulty was experienced by the makers of mechanical transport vehicles in obtaining the necessary sets of bearings until early in the

[1] D.M.T./1/E/20.
[2] See above, p. 24.
[3] D.M.T./1/S/11.
[4] Hist. Rec./H/1920/3.
[5] *Ibid*, pp. 16–17; Vol. VIII, Part III, pp. 72–91.

year 1917, when the supply began to come forward less freely by reason of a reorganisation of Messrs. Hoffmann's output, which was instituted by the Small Tools Department with a view to providing for the increasing demands for ball bearings to meet other requirements, such as the manufacture of aircraft and tanks. Upon the organisation of the supply of bearings by the Ministry, it was arranged that the Mechanical Transport Department should notify its requirements to the branch concerned, and that the output from Messrs Hoffmann's works should only be allocated to contractors of relatively high importance. It was found impracticable to re-design bearings for mechanical transport vehicles, as the delay caused by consequent changes to gear boxes and back axles would have been prohibitive, and the interchangeability of parts would also have been affected. It was, however, practicable to limit the number of spare bearings for motor vehicles which were being purchased by the Russian Commission in excess of their actual requirements; and from July, 1917, onwards the efforts made by the Ball Bearings Department of the Ministry successfully prevented the extremely difficult position in regard to this supply from having any very serious effect upon the output of vehicles.

IV. The Supply and Storage of Tyres.

Tyres, both solid and pneumatic, were required in enormous quantities during the war for the maintenance of mechanical transport vehicles in Government service and as reserves. When the Ministry began to deal with the provision of mechanical transport supplies, the section concerned obtained a schedule from the Home Depot showing the quantity of tyres required by them weekly according to sizes. The quantities of this schedule were based on the average weekly demands for each size of tyre over a period of three months.[1] The schedule showed that between 20 and 30 different sizes of solid band tyres were then being demanded from the front, and that the total average weekly demand amounted to about 5,400 tyres per week, but, as stocks had fallen low, it was considered necessary to obtain, per week, three times the average weekly quantity demanded.

Up to that time contracts had been placed for 5,684 solid band tyres per week, together with 13,500 from the United States, which had been ordered to meet an urgent demand for two American sizes. The English manufacturers at the time could only make about 7,200 solid band tyres per week, but one of the largest manufacturers was making extensions and expected to be able to supply an extra 4,000 tyres per week within about two months. It was calculated that a total of 11,200 solid band tyres could then be obtained per week. Other firms had, however, indicated that with assistance from the Ministry in the matter of labour they could increase their output, so that it appeared possible that the full quantity of solid band tyres required could eventually be obtained in this country.

[1] D.M.T./1/T/4.

In regard to pneumatic covers, the schedule showed that the average weekly demand for both grooved and steel-studded covers amounted to about 9,100, ranging over about 20 sizes, the full quantity being divided into about 5,500 grooved covers and 3,600 steel covers.

Here again stocks had fallen low, and until these were raised to a satisfactory position the requirements equalled three times the average weekly number demanded. It had been ascertained that the available output of manufacturers in this country was approximately 18,000 pneumatic covers per week, and up to that time approximately 12,000 per week had been ordered, and though no orders for weekly quantities of motor cycle tyres had been placed, it appeared possible that the manufacturers could meet the full demands.

In the case of inner tubes the same method was used to arrive at the number per week required from manufacturers. The average weekly demands, covering 33 sizes, amounted to 8,611 tubes per week, and three times this number were required per week. Orders had been placed up to date for 14,685 tubes per week, and it had been ascertained that the manufacturers as a whole were quite capable of meeting the full requirements.

The weekly orders for solid band tyres and pneumatic covers and tubes were, therefore, increased to the fullest possible extent, the whole output apart from that required for new vehicles being taken. Within three months, *i.e.*, in December, 1916, the position in regard to pneumatic covers and tubes had so far recovered that it was possible to reduce the orders to one-third, *i.e.*, a figure level with the normal demand. Subsequently, the method of obtaining supplies of tyres by running contracts was abandoned in favour of the placing of orders for firm quantities from time to time as necessity arose.

In contracts placed with the various tyre manufacturers in October, 1916, a clause was inserted providing that at the end of every four weeks the order for any undelivered balance should be automatically cancelled. This clause was inserted in order that the records of the home depot might be kept correct. Against this advantage, however, the method had the effect of abolishing any check on the manufacturers as to delivery, as there was no means of forcing them to deliver the full quantity ordered, such as buying in the open market against them. By the autumn of 1917, tyre contracts were in the utmost confusion. A number of the manufacturers had contracts in hand for tyres which they could not deliver, and many contracts which were cancelled from month to month were never begun at all. One firm held contracts for ten times the number of covers they were turning out and were still receiving new contracts. It was impossible to form any estimate of deliveries. In the case of nearly all the firms, output was seriously decreasing owing to the calling up of labour, and in this particular supply, labour and not plant was the limiting factor. Large demands for tyres and tubes made by the home depot at about this time could not be met in full in this country, and the Ministry was compelled to place orders in America, France, and Italy.

In February, 1917, a deputation of the Solid Tyre Committee of the Society of Motor Manufacturers and Traders visited France for the purpose of examining the conditions under which solid rubber tyres were used and the arrangements made for their handling, storage, and fitting. This visit was productive of very useful results, both to the manufacturers and to the Ministry. The performance of various makes of tyres under war conditions were notified by the War Office to the Ministry as a guide in placing orders and also in dealing with the question of prices.

A certain percentage of the solid band tyres sent overseas burst when being pressed on, and these were replaced by manufacturers under a system whereby a section was cut out through the faulty place of each tyre which burst, and sent home with a certificate giving the pressure at which the tyre burst. This evidence was then placed before the manufacturer concerned, in order that replacement could be effected.

Towards the end of 1917 an attempt was made to have all wheel rims and tyre bands for solid rubber tyres standardised as far as concerned supplies for the use of the Government, by bringing them within the British standard dimensions laid down in Report No. 71 of the Engineering Standards Committee, 1917, and wheel and tyre firms were circularised in order to bring this into effect as from 1 December, 1917. For one reason and another, however, it did not become possible for all manufacturers to conform to the request, and therefore this effort to bring about standardisation failed. The principal difficulty was to secure the necessary accuracy of workmanship entailed in supplying wheels to the specified 1 mm. tolerance on the circumference. The tolerance formerly allowed had been 3 mm. and with the diluted labour available the requisite degree of accuracy was believed to be unattainable. No standard tapes or gauges were then in existence for the new sizes, and in many cases the manufacturers had large stocks of the old sizes on hand.

A large store at Camden Town under the control of the Home Mechanical Transport Depot was utilised by the War Office for tyres delivered by the manufacturers. Early in 1917 this store became congested, and arrangements were made by the Ministry with the tyre manufacturers to store the surplus tyres on their own premises. Such tyres, after having passed inspection by the inspecting officers of the Mechanical Transport Department of the Ministry, were placed in the stores provided at the manufacturers' works, and paid for by the Ministry on production of documents bearing the inspecting officers' certificates of inspection and delivery into stores. Withdrawals from this stock into the Camden Town store were carried out by direct notice to the manufacturers from the Home Mechanical Transport Depot, but in the case of two of the largest firms concerned, arrangements were made for a representative of the home depôt to be stationed at works, with power to give the necessary instructions to the firms to despatch tyres overseas or elsewhere direct from stock.

V. Materials.

The most important materials used in mechanical transport construction are aluminium, alloy and other steel, copper, and cast-iron. All these were under Ministry control,[1] and the Mechanical Transport Department exercised no distinct control over the supplies to its contractors. Considerable assistance was, however, given both by intervention in regard to priority and by the personal activities of inspecting officers.

(a) Action to Supplement Contractors' Provision of Material.

When mechanical transport contractors experienced exceptional difficulty in obtaining material, the Mechanical Transport Department made representations to the Priority Department of the Ministry or to the department controlling the supply of the particular material required. Assistance was thus obtained for the firms either in the form of higher priority or in the nature of information as to where supplies were obtainable. Early in 1918 an arrangement was made whereby a representative of the Mechanical Transport Department attended the weekly meeting of the Priority Committee and brought to its notice cases of exceptional difficulty. The Priority Committee then considered each case and dealt with it according to its merits. The committee also provided a list of applications received directly from the firms for higher priority in regard to the material required for the manufacture of mechanical transport supplies, in order that the Mechanical Transport Department might give information as to the degree of urgency applying to each.

The inspecting officers of the Mechanical Transport Department also assisted contractors to find sources of supply of material and to obtain quick delivery.

(b) Special Arrangements in regard to Steel and Aluminium.

In January, 1917, the Director of Mechanical Transport drew the attention of all mechanical transport vehicle contractors to the "British Standard Specifications for Wrought Steel for Automobiles" as contained in the British Engineering Standards Committee's Report No. 75, which had been drawn up to cover practically all the requirements for constructing motor vehicles. The contractors were informed that it was hoped that they would be able, in the immediate future, to specify one or other of these steels in purchasing materials. It was pointed out that the supply of steel for motor construction would thereby be very greatly facilitated, and steel manufacturers would be released from making small quantities of steel to differing specifications furnished by the various motor manufacturers. It was anticipated that labour and material would thus be economised. The replies received disclosed the fact that in some cases steel conforming to these

[1] *See* Vol. VII, Parts II & III.

standard specifications was already being used and gave promise that in the remaining cases this would be done as soon as was practicable.[1]

The matter was then brought to the notice of the Director of Steel Production, and taken up by the Metals and Materials Economy Committee in an endeavour to arrange for steel to these standard specifications to be utilised in aircraft production also. This was successfully arranged, and the adoption of these standard specifications for aircraft and mechanical transport production did much towards simplifying the supply of steel generally.

When in July, 1917, the Director of Steel Production introduced a system of prefix letters to denote the demands for making specific stores, the distinctive letters in the case of the mechanical transport were "M.C.B." in respect of supplies for the British Government, and "M.C.A." in respect of supplies for Allied Governments. As the Mechanical Transport Department did not place any direct orders for steel, it was necessary to notify all their contractors that these prefixes were to be employed in the case of all orders for steel either placed and unexecuted, or to be placed by them and their sub-contractors. In accordance with the general method of allocation periodical returns from the steel-rolling mills showed what quantities were required for mechanical transport as denoted by these prefixes and facilitated the final allotment of steel for the purpose.

During the winter of 1916–17 the supplies of aluminium available for motor transport vehicles were considerably less than the demand. In January, 1917, the apportionment of aluminium against the various requirements showed that 2,250 tons were allowed for mechanical transport for the year 1917, as against an estimated requirement of 4,500 tons. In consequence, it became necessary to obtain particulars from every firm manufacturing mechanical transport vehicles for the Government of the various parts in which aluminium was utilised and suggestions as to the use of alternative materials. The substitution of other metals for aluminium was then decided upon, but it was only possible to effect the alterations gradually, owing mainly to the time taken in devising new patterns. By this arrangement, however, the requirement of aluminium alloy, which was the only form used in the construction of motor vehicles, was kept within the 2,250 tons available.[2] The position was further eased towards the end of 1917, when the introduction of a new method of treating aluminium scrap opened up a fresh source of supply which was suitable for certain mechanical transport purposes.

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[1] D.M.T./1/S/24.
[2] D.M.T./1/A/2.

CHAPTER V.

HORSE-DRAWN TRANSPORT AND PEDAL BICYCLES.

I. Administrative Machinery.

The responsibility for the supply of horse-drawn transport and pedal bicycles for the Army rested with Section A.3 of the Directorate of Artillery, and contracts were arranged by the Contracts Section 3. When war broke out there was great difficulty in getting transport vehicles quickly. An attempt to expedite delivery by ordering bodies, wheels and axles separately was not successful, but by getting the large railway wagon firms and leading agricultural engineers to compete for complete vehicles large quantities were soon secured, and by the middle of 1915 the competition for contracts for wagons with wooden bodies had become keen. For some time it was not easy to get firms to make the special vehicles requiring metal frames or fittings, such as travelling kitchens, water-tank carts, cable and telephone wagons, but after the first difficulties had been overcome supply was easy.[1]

A section of the Ministry (C.M.5) was formed to deal with this supply which was transferred in June, 1915. When the initial difficulties had been overcome, at about the end of April, 1916, this supply was handed over to a section of the Contracts Department, to which one of the technical assistants was transferred.[2]

The supply of pedal bicycles, with the assistant in charge, was transferred on 10 April, 1916, to the section dealing with small arms, machine guns, etc., as their inspection had throughout been under the direction of the Chief Inspector of Small Arms.[3] In July, 1917, this supply was vested in the Mechanical Transport Department of the Ministry. Demands were made in the normal way by Section A.3 of the Directorate of Artillery, and requirements were met mainly by running contracts placed by the Contracts Section P.M.4. Inspection continued to be carried out by the Inspector of Small Arms, and complete machines and spares were delivered to the Deputy Director of Ordnance Stores, Woolwich.[4]

II. Methods of Supplying Horse-drawn Vehicles.

When the Ministry assumed control over the supply of horse-drawn vehicles many of the firms who in normal times built railway rolling stock, agricultural implements, and road vehicles were already

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[1] C.R. 2425.
[2] Hist. Rec./H/1860/5.
[3] *Ibid.*
[4] D.M.R.S. 330 B.

engaged on Government contracts, and in order to secure the large number of wagons and carts then required, the services of additional firms had to be requisitioned. Many of the firms had not the necessary plant, especially for the production of wheels, axles, and stampings, and a number of machines had to be installed before these parts could be obtained. As there was no return available as to the description of plant and tools which already existed in the different works, a good deal of time was lost in compiling particulars and starting up the firms. Another source of trouble was the difficulty in securing gauges. After the majority of the firms had secured the necessary plant and labour, it is possible that better deliveries would have been obtained and waste of labour and plant avoided had the method of open tender been discontinued and had contractors been given continuous work at an agreed price under an agreement to terminate the contract by notice. The practice of fixing contracts by open competition no doubt tended to keep down prices, but it was most uneconomical in other directions, as firms which had been engaged in building a particular type for perhaps three months were not always successful in getting a second contract for the same type of vehicle. Starting on a new type entailed the provision of new gauges, jigs and templates and alterations to plant. Moreover, since firms were practically at the end of their contract before fresh orders were placed, this practice often entailed delay and difficulty in obtaining materials. Delay was also caused in some instances by modification in design to meet military requirements, and by the substitution of alternative materials owing to those specified being unobtainable.[1]

III. The Production of Pedal Bicycles.

The military pattern of pedal bicycle had proved to be the most satisfactory, but considerable time elapsed before the necessary supplies of this type could be obtained, and in the meantime machines of various trade patterns were purchased for Army use. The reason of this shortage of standard machines is to be found in the fact that the Birmingham Small Arms Company, which had turned to the manufacture of cycles in time of peace, was the only firm having the requisite gauges, fitments, and tools. The policy was gradually adopted of placing orders with a few only of the best contractors, who were thus in a position to purchase the necessary materials many weeks in advance.[2] The standard Mark IV was by the spring of 1917 the only type in demand, and production was limited to four firms.

In March, 1917, the requirement for these cycles was 200 a week, but the supply branch was asked to preserve facilities for expansion beyond this, and was urged to increase supplies of spares, the income of which was not equal to the needs of the Army. The parts specially required were front brakes, fork clips, chains, handle bars, rubber pedals, wheels, and front rims. The requirement of tyre covers and

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[1] HIST. REC./H/1860/5.
[2] HIST. REC./H/1860/5; cf. HIST. REC./R/1124/14.

inner tubes was 5,000 of each per month. Demands for pedal bicycles increased very rapidly during the summer of 1917. In July, just after the Mechanical Transport Department had taken over supply, the requirement for bicycles was increased to 500 per week, and for outer covers and tubes to 8,000 per month. The Contracts Branch experienced considerable difficulty in getting contracts placed, owing to the Birmingham Small Arms Company and the Enfield Cycle Company quoting over £1 per machine higher than formerly, while the James Cycle Company advanced the price only 4*s*. Further delay occurred in getting supplies of raw material, and in September the position was very unsatisfactory. Requests had come from General Headquarters, France, that the supply of bicycles should be expedited as much as possible, as it was desired to authorise the issue of bicycles for certain fresh services.[1] The average acceptances from 1 July to 22 September, 1917, had been only 151 per week, while the weekly issues over the same period were 687. This led to a dangerous depletion of stocks. The James Cycle Company which, by 26 October, should have completed 1,400 machines had failed to deliver any, and the question of price made it difficult to transfer the contract since Messrs. James' price was £5 16*s*. 0*d*. per machine, against the Birmingham Small Arms Company's and the Enfield Cycle Company's price of £7 3*s*. 0*d*. and £7 1*s*. 6*d*. respectively. In October the Army requirement for outer covers and tubes was increased to 10,000 a month. In view of the shortage of supply it was decided to maintain the trade pattern push bicycles which had been issued to the troops. This necessitated the provision of a quantity of spare parts. In November the Director of Artillery formulated a demand for 700 Mark IV bicycles a week during the period January to April, 1918, and increased the demand for outer covers and tubes to 15,000 a month.[2] The weekly requirement of bicycles was further increased in June, 1918, to 1,500.[3] Though the required weekly output was never attained, in the summer of 1918 output reached more than 1,000 per week.

Various bicycle accessories, such as saddles, tool bags, etc., were purchased separately and allocated to the cycle makers as required.[4]

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[1] D.M.R.S. 330 B. [2] *Ibid.*
[3] (Printed) *Weekly Report*, No. 144, Part II, Table XI (1.6.18).
[4] Hist. Rec./H/1860/5.

CHAPTER VI.

REVIEW.

I. Total Deliveries.

The table which follows shows the numbers of various classes of vehicle which were acquired by the War Office and the Ministry during the war. The figures of deliveries show no very striking instances of increased production during the period 1917–18, the firms having settled down to a fairly steady output soon after the Ministry assumed control of supply.

DELIVERIES OF MECHANICAL TRANSPORT VEHICLES.[1]

	Acquired by War Office from outbreak of war to 1 September, 1916.	Acquired by Ministry of Munitions from 1 September, 1916, to December, 1918.	Total.
Lorries (heavy and light)—			
British makes	13,585	24,460	38,045
Foreign makes	8,120	12,835	20,955
3-ton British Quad (F.W.D.) Chassis.	—	490	490
Cars, Vans, and Ambulances—			
British makes	6,330	7,120	13,450
Foreign makes	3,300	17,050	20,350
Motor Cycles	18,750	22,300	41,050
Steam Wagons..	440	714	1,154
Miscellaneous Vehicles ..	—	—	1,569
Tractors	936	2,505	3,441

At the outbreak of war the entire British Army possessed less than 100 motor lorries,[2] and the total number of the chief makes acquired from the outbreak of war until December, 1918, was about 34,000; the corresponding number of cars, vans, and ambulances being approximately 59,000.

Dependence on American supplies was very marked throughout the war in the case of lorries and the Ford productions. Of the total number of lorries of all descriptions, 19,360 were produced in America, and during the war 18,300 Ford cars, ambulances, and vans were acquired by the British Government. Some two thousand different

[1] HIST. REC./H/1920/2. Appendix III. These figures exclude comparatively small quantities of less important makes.
[2] D.G.I.M./Gen./016.

parts are used in the construction of a 3-ton motor lorry, and when consideration is taken of the number of different types of vehicle in use, it will readily be understood that the output of spare parts cannot be shown.

II. Manufacture for the Allies.

In addition to these enormous numbers of vehicles purchased for the British forces, large quantities were obtained from British makers on behalf of the Allies, notably for Russia. In May, 1916, the Russian Government approached the War Office with a request for large supplies of motor transport vehicles. Various orders had been placed previously by the War Office for Russia, but the new demands were on such a large scale that the Director of Army Contracts thought it desirable, in view of the large questions of labour, plant, and raw material involved, that the work of supply should be transferred to the Ministry. As has been seen above, it was agreed that Mr. Rainforth should take over the work of purchasing for the Russian Government. The requirements were for 20,000 motor four-wheeled vehicles of all kinds, including armoured cars, and 15,000 motor cycles; and the Treasury were asked to sanction the expenditure of £2,000,000 a month against the orders.[1] The difficulty of providing shipping freight made it appear desirable that the chassis only should be supplied from this country or America, the bodies being made in Russia, and that the chassis should be partly dis-assembled before shipment, since the complete chassis occupied double or three times the space. The entire absence of any reliable data as to the facilities for body building or for assembling and producing the necessary spares in Russia made it extremely difficult for British authorities to decide how far it would be advisable to meet the Russian demands. The War Office was at that time engaged upon a census of the motor industry, with a view to reorganisation, and the Russian Government was informed that the required motor cycles could be supplied, but that no answer could be given as to lorries and cars pending the results of the census. In August, Mr. Rainforth was authorised to proceed with manufacture for Russia of 3,000 3-ton lorries and up to 2,000 touring cars. By September the Russian representative had been furnished with information as to the capacity for building bodies in Russia. It was stated that 7,000 bodies could be built by July, 1917, and the War Office agreed that the British Government should provide chassis for such bodies as could be manufactured in Russia by July, 1917, up to a maximum of 7,000, and would consider how far this number could be increased in the event of its being possible to manufacture a greater number of bodies in Russia by that date. This undertaking was, of course, subject to the necessary freight being available.[2] It was found, however, in October that it would not be possible to make the promised number of chassis in this country; moreover, it seemed very doubtful whether the Russians would be able to produce the necessary bodies and do the final assembling, so that the whole programme needed modification. It was practically impossible for the Director-General of Mechanical Transport to make

[1] C.R. 4541. [2] Hist. Rec./R/1921.3/1.

any statement at that time regarding British output, as the necessary extensions had not been made, but it appeared that 3,000 chassis might be built in England, and it seemed doubtful whether tonnage would be available for the shipment of more than that number. As a result of the steps taken to increase the output of British-made lorries, it appeared at the end of 1916 that there would, by about April, 1917, be a surplus over the requirements of the British Government. The Russian representatives were therefore asked to indicate what types would be acceptable to the Russian Government. After exhaustive tests it was found that the Leyland, Thornycroft, Dennis, and Associated Equipment Company lorries were suitable to their requirements, subject to slight modifications. As a result a promise was given to the Russian Commission that the Ministry were prepared to meet the Russian requirements to the extent of about 800–900 3-ton lorries by 30 September, 1917.[1] Difficulty and delay in obtaining increased output and unforeseen requirements of the British Government prevented the fulfilment of this promise, and during 1917 only 377 lorries were shipped to Russia. This number could and would have been exceeded had it not been for difficulties of shipment.[2]

As regards armoured cars and motor cars, the position was partly met by an extension of Messrs. Clement Talbot's works, but the number shipped did not bear any relation to the number asked for. Though enquiries were made in the summer of 1916, it was not until 23 January, 1917, that the motor cycle contracts for Russia were completed, and they stipulated for monthly deliveries in specified quantities, with the proviso that " the Minister does not undertake to accept any motor cycles not delivered by 30 June, 1917." By April, 1917, it was apparent that this clause in the contracts would involve the firms in financial difficulties, as it was clear that delivery could not be made in the time. Applications for extension of the time limit were refused, and by 30 June only 4,315 machines had been delivered out of a total of 8,394 ordered. For a further 494 extension of time had been specially granted at the request of the Russian Government, leaving a balance of 3,585 machines. The latest advice from Russia was that the maximum number of machines required was only 5,424. The makers were thus left with numbers of unwanted machines in an advanced state of manufacture. The cycles were of 6 horse-power and 8 horse-power, and were totally unsuited for the purposes of the British Army, whose standard machine was of 4 horse-power, and it appeared that there would be no sale for such high-power cycles in overseas markets. The financial position of the firms who had failed to complete their contracts was critical, as in some cases they had borrowed heavily to purchase material. Many of the firms were merely assembling establishments, and had no machinery suitable for other work. With the exception of a further 615 machines which the Russian Government were prepared to accept, the Ministry refused to take any cycles after the agreed date, but consented to grant export permits for any machines which the manufacturers elected to finish.[3]

[1] HIST. REC./H/1920/1. [2] HIST. REC./H/1920/2. [3] D.M.T./1/A/38.

After the Russian defection a considerable amount of motor transport originally ordered for them became available to meet War Office requirements, and helped to ease the situation with regard to transport in the spring of 1918.[1]

In addition to the assistance given to Russia in providing mechanical transport, it will be seen from the following tables that considerable supplies were also provided for the other Allies.

MECHANICAL TRANSPORT SUPPLIES TO THE ALLIES.[2]

Ally.	Description of Store.	Total Supplies prior to 31/12/16.	1917.	1918.	Total 1914–18.
Belgium ..	Motor Cycles ..	1,432	546	42	2,020
	Bicycles	13,309	8,731	821	22,861
	Lorries	770	3	43	816
	Motor Cars, Chassis, and Vans	128	149	75	352
	Ambulances ..	62	—	—	62
	Side-cars	390	—	—	390
France ..	Motor Cycles ..	2,253	2,400	1,907	6,560
	Side-cars	154	1,500	2,186	3,840
	Bicycles	—	11,000	6,245	17,245
	Motor Cars ..	25	—	12	37
	Lorries	1,171	—	—	1,171
Italy ..	Motor Cycles ..	829	—	406	1,235
	Bicycles	1,200	—	—	1,200
	Motor Ambulances	3	—	—	3
	Lorries	—	—	30	30
	Holt Tractors ..	—	—	20	20
	Caterpillars.. ..	—	—	89	89
Rumania ..	Motor Ambulances	139	38	—	177
	Motor Cycles ..	300	80	—	380
	Side-cars	—	68	—	68
	Bicycles	—	650	—	650[3]
Russia ..	Motor Cars ..	868	236	—	1,104
	Motor Cycles ..	2,510	4,903	—	7,413
	Side-cars	300	2,262	—	2,562
	Armoured Cars ..	165	54	—	219
	Ambulances ..	—	4	—	4
	Lorries	749	377	—	1,126
	Wagons	—	1,046	—	1,046
	Tractors	9	510	—	519
U.S.A. ..	Motor Cars and Chassis	—	38	512	550
	Motor Cycles ..	—	137	427	564
	Ambulances ..	—	—	68	68
	Motor Vans ..	—	2	481	483
	Bicycles	—	—	727	727
	Lorries	—	84	4,222	4,306
	Side-cars	—	118	209	327
	Transport and G.S. Wagons	—	—	864	864
	Holt Caterpillars ..	—	—	64	64

[1] D.M.R.S. 600 R. [2] Hist. Rec./R/1010/32.
[3] 37 re-shipped to United Kingdom, 1917.

Large numbers of lorries and bicycles were supplied to the French and Belgium Governments during the first two years of the war. The contribution to Italy consisted chiefly of motor cycles and bicycles and to Rumania of motor ambulances and motor cycles. A large number of lorries, bicycles, motor cycles, and transport wagons were supplied to the American Government in 1918, as equipment for the American troops sent to France in that year.

III. Main Features of Mechanical Transport Supply.

The story of the supply of mechanical transport presents no instances of the adoption of novel methods of obtaining production. The motor industry was well established in England before the war, the vehicles were of more or less standard types, and required no important modifications to render them fit for war service. The main difficulty in supply throughout the war was scarcity of labour, to which was added later shortage of material owing to the low priority granted to mechanical transport work, and to the encroachments made by aircraft and tank requirements upon similar classes of capacity and materials. One of the first steps taken by the Ministry when it assumed responsibility for supply was to prohibit manufacture and sale, except under licence, in order to prevent the use of capacity for other than war purposes. No national factories were established, and the method of group manufacture under departmental control, so often applied with excellent results by the Ministry, was adopted only in the case of the tractors produced under the Director of Munitions Mechanical Transport. Thus, methods of supply continued with little change throughout the war, and this is no doubt largely due to the fact that, in spite of the change in controlling authority, the personnel to a great extent remained the same under the two departments.

Vehicle makers were accorded a free hand as to the placing of sub-contracts, with the result that sub-contractors often undertook liabilities which they were unable to discharge. The Department was, however, able by the exercise of a certain amount of diplomacy to prevent any serious breakdown in supply on this account. Sub-contractors of motor builders covered almost all the mechanical trade, but mechanical transport supply does not provide any notable instances of firms entirely new to this type of work undertaking it for war service. As supplies of components and accessories became more difficult to obtain the firms became to a certain extent dependent on the Ministry for these items, but no definite rules existed as to their issue. Tyres, engines, and tools were provided by the Ministry in certain cases, but it was more usual for the maker to supply the vehicle complete.

The provision of the spares required by the Army was one of the greatest difficulties of the Supply Department. The demands were so far in excess of peace-time requirements that the manufacturers' works were not laid out for the production of spares on the scale required. The fact that repair of vehicles was at no period of the war

dealt with by the Ministry made the situation more difficult, as the Department could exercise no control over the use of spare parts in effecting repairs, and the impression was widespread that parts were replaced with undue frequency.[1] It was, however, maintained[2] that the transference to the Ministry of the responsibility for all repairs to mechanical transport, overseas as well as at home, was impracticable, since it would tend to undermine the authority of the War Office. Similarly, the difficulty experienced in estimating wastage gravely hampered the formulation of a regular programme of manufacture, which was in any case almost impracticable in providing a store for which unexpected demands frequently arose.

The British Army was first equipped with subsidised vehicles in accordance with a scheme of long standing. Additions were subsequently made from the output of established British makers and by means of large purchases in the United States. With increased demands and the growing needs of other stores, such as aircraft and tanks, which required a similar class of manufacturing capacity, mechanical transport for the Army could only be supplied by severely restricting manufacture for private use. This was effected by the Control Orders of 1916 and 1917. Independence of overseas supplies was difficult to attain in face of an ever-increasing requirement. In the year 1918 the difficulty of the problem of supply grew more serious. On the one hand, the establishment was increased to meet the exigencies of open warfare; on the other, the accumulation of large numbers of vehicles for repair added to the difficulty of organising the production of spare parts alongside the manufacture of complete vehicles.

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[1] D.M.R.S. 430 B. [2] 1/Gen. No./2236.

APPENDIX.

APPENDIX

(CHAPTER III, p. 32.)

Orders Controlling the Manufacture of Motor Engines, Cycles, and Vehicles.

(*a*) ORDER PROHIBITING THE MANUFACTURE OR ERECTION OF MOTOR ENGINES, CYCLES, OR VEHICLES, 3 NOVEMBER, 1916.

The Minister of Munitions hereby gives notice that in exercise of the powers conferred upon him by the Defence of the Realm (Consolidation) Act, 1914; the Defence of the Realm (Amendment) No. 2 Act, 1915; the Defence of the Realm (Consolidation) Regulations, 1914, and all other powers thereunto enabling him, as from the 15th day of November, he hereby prohibits, until further notice, any person, firm or company engaged in the manufacture or repair of any vehicle designed for mechanical transport or traction, or any part of such vehicle, from carrying out in any factory, workshop or other premises, without a permit issued under the authority of the Admiralty, the Army Council or the Ministry of Munitions, any work consisting in the manufacture, assembling or erection of any new or unused motor internal combustion engine, designed or adapted for mechanical traction, or of any new or unused motor cycle, motor chassis, motor wagon or of any tractor or other motor vehicles of any kind propelled by mechanical means, subject however to the following exception :—

Work required to complete contracts placed by the Admiralty, the War Office, the Minister of Munitions or an Allied Government on or before the date of this Order.[1]

(*b*) THE MOTOR ENGINES AND VEHICLES ORDER, 1917, DATED 6 JANUARY, 1917.

The Minister of Munitions hereby gives notice that in exercise of the powers conferred upon him by the Defence of the Realm (Consolidation) Act, 1914; the Defence of the Realm (Amendment) No. 2 Act, 1915; the Defence of the Realm Regulations, and all other powers thereunto enabling him, as from the date of this Order, he hereby prohibits, until further notice, any person, firm or company from carrying out, without a permit issued under the authority of the Admiralty, the Army Council or the Minister of Munitions, any work consisting in or connected with the manufacture, assembling or erection of any new or unused motor internal combustion engine, designed or adapted for mechanical traction, or of any new or unused motor cycle, motor chassis, motor wagon, or of any tractor or other motor vehicles of any kind propelled by mechanical means, subject, however, to the following exception :—

Work required to complete contracts placed by the Admiralty, the War Office, the Minister of Munitions or an Allied Government on or before the 3rd day of November, 1916.

For the purpose of this Order the expression " assembling " shall be deemed to include the placing or replacing in position of any part.

The Order, dated 3 November, 1916, published in the *London Gazette*, of 10 November, 1916, is hereby cancelled, without prejudice to anything done thereunder.

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[1] This Order was cancelled in January, 1917, and replaced by the Motor Engines and Vehicles Order, 1917.

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VOLUME XII

THE SUPPLY OF MUNITIONS

PART V

RAILWAY MATERIALS AND ROPEWAYS

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CHAPTER I.

INTRODUCTION.

The history of the supply of railway material as a military store falls into three main periods, each succeeding one being of far greater urgency than the last. The first period was one of comparative unimportance. Only small orders for rolling stock and track were placed, home and foreign demands were light, and the workshops of the railway companies themselves were filled with munition work. The second period, beginning at the end of 1915 with French demands for rolling stock, was marked by large Allied demands, especially from Russia, where events in Poland were expected to lead to an enormous railway programme. During this period British demands also began to increase and grew steadily until September, 1916.[1] The third period opened with the enormous demands for the British forces in the autumn of 1916, after which Allied demands sank into the background, although large quantities of railway materials were supplied to France in 1918. By this time there was practically no industrial capacity to which some urgent war demand had not staked out a claim, and the first problem was to recover some of the railway capacity which had been allocated to other military stores. The period of 1917 was one of large purchases from abroad and struggles at home for priority in railway shops. The characteristic of 1918 is not so much a struggle for capacity as for material, for with the cut in the iron ore imports and with the Admiralty demands for plates for merchant shipbuilding the original allocation of steel for railways was entirely inadequate to meet the demands for the overseas forces or for the home railways, which by this time were in urgent need of material. The events in France during the spring and summer necessitated a largely increased programme, and when, at the end of the year, the 1919 steel budget was planned[2] the tonnage of steel allocated to both home and overseas railways was equal to the allocation for tanks.

I. Developments in the Military Use of Railway Material, 1916-1918.

(a) Broad-gauge Lines.

During the first two years of the war, it was expected that the French railways would suffice to deal with the traffic of the British Army on the western front. Moreover, the practically stationary position of the fighting line led to no great demand for the relaying

[1] *See* below, p. 19.
[2] *See* below, p. 34.

of railways, which would have been destroyed by the enemy in the event of an Allied advance through Belgium. This factor was considered mainly in connection with large supplies desired by Russia for the campaign in Poland during 1916. In 1915 and 1916, Great Britain supplied the French Government with more than 150 locomotives and 2,300 tons of railway material,[1] but the amount of railway material supplied for British military railways was comparatively small. In the summer of 1916, the need for rails and rolling stock was immensely increased by the enormous growth in the quantities of munitions to be transported. The survey of transportation in France made by Mr. (afterwards Sir Eric) Geddes in August and September of that year resulted in a new manufacturing programme of 1,200 miles of standard gauge and 1,000 miles of light railway track with rolling stock to correspond. During the following winter, the Commander-in-Chief continued to press for additional rails and rolling stock, not only in case of an advance in the following spring, but also because he was about to take over the operation of certain French lines. In May, 1917, an additional 1,000 miles of standard gauge track was added to the previous requirement.[2]

During the year 1917 vast advances were made in the rate of unloading at French ports. These were partly due to improvements effected in transport from port by means of increasing the numbers of locomotives and wagons employed. The rate of discharge from ships rose from 10 tons per ship per hour in February, 1917, to 37·5 tons per ship per hour in the following May, and the total tonnage handled increased from 130,000 tons per week to 225,000 tons per week.[3] This expansion did not cease with 1918. The volume of return traffic increased with the Ministry's schemes for salving military material. American troops and supplies arrived in France in advance of their transport arrangements, which had to be supplemented from Great Britain. Immense losses were experienced during the spring retreat. Increased rolling stock was needed for transporting troops and stores overland to the East and for sending coal through France to Italy.[4] In May, 1917, an average of 52·25 miles of new broad-gauge lines had been opened for traffic in each week. The advances of October, 1918, gave rise to still greater activity in this direction. The retiring enemy destroyed the railway with extreme thoroughness. During a single week in October, 148 miles of track were reconstructed and over 57 miles of new material were used for the purpose. The total length of the new broad-gauge lines constructed by the British Army in France was roughly 2,000 miles, and during the last six months of 1918, 1,581 miles were also reconstructed. Ultimately, the military rolling stock in France amounted to 1,400 broad-gauge locomotives and wagons equivalent to 70,000 10-ton units, as well as ambulance trains and trains for personnel.[5]

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[1] Hist. Rec./H/1010/3.
[2] *See* below, p. 27.
[3] Hist. Rec./H/1910/5.
[4] *See* below, p. 33.
[5] Hist. Rec./H/1910/5.

(b) LIGHT RAILWAYS.

In addition to the broad-gauge lines, an entirely new system of light railways was developed as the devastation of the immediate theatre of war increased the difficulties of road transport, and as the quantities of stores to be carried to the front line grew. The mobility of the entrenched army depended partly upon this new network of light railways and partly upon the motor transport columns used to carry stores from railhead.[1] Ultimately, as many as 1,000 miles of light railway were under operation along the western front, and during the German advance in 1918 they carried over 250,000 tons in a single week. The volume of traffic over these light lines reached an average of 160,000 to 180,000 tons weekly during several months in 1917 and 1918.[2]

(c) THE AERIAL ROPEWAY.[3]

The light railway or motor transport column carried forward stores and munitions from railhead to the zone of crater-land behind the front line. In some sectors this zone was so cut up by shell craters and, in winter, so bebogged that neither the light railway nor the motor-lorry could attempt to cross it. By 1917 it was 8 miles deep and all stores had to be carried across it by men or mules under heavy fire. Several efforts were made to provide some less arduous means of transporting stores across this area. The cross-country tractor which was developed has been described elsewhere.[4] About July, 1917, projects were set on foot for the use of an aerial ropeway for this purpose. Two types were developed, the Hamilton or military ropeway with strong steel posts, standard lengths of 100 yards, and with sectional anchorages to facilitate repair under fire, and the Leeming system, for which provisional patents were taken out by Captain J. A. Leeming and other officers in the Outside Engineering Branch of the Trench Warfare Supply Department. The Leeming ropeway was of lighter construction than the Hamilton, and allowed for no sectional anchorages in case of cutting, but could be readily repaired. It was collapsible, being intended mainly for use by night, and was adapted for mechanical haulage, either by small petrol engines or by the standard War Department motor-lorry. In military opinion, the Hamilton ropeway was best suited for forward work and short advances, the Leeming for use under more favourable conditions. A formal demand for 100 miles of the one and 50 miles of the other was made in November, 1917; but supply was considerably delayed and comparatively little use was made of the units which were issued before the close of hostilities.[5] The cessation of trench warfare in the spring of 1918 had, indeed, removed their primary purpose. During the summer of 1918, however, manufacture of the ropeways was hastened, with a special view to facilitating the transport of chemical warfare stores.

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[1] For the supply of Motor Transport, *see* Vol. XII, Part IV.
[2] HIST. REC./H/1910/5.
[3] W/22; M.E./L./194; HIST. REC./R/1660/13; HIST. REC./H/1600/14, Chap. V.
[4] Vol. XII, Part IV.
[5] *See* below, p. 36.

II. Critical Position of the Home Railways, 1917-1918.

The military railways in France were developed largely at the cost of home and colonial railways. In 1916 and 1917 the normal mileage of lines relaid in the United Kingdom was enormously reduced. The replacement and repair of locomotives were very considerably restricted. Towards the end of 1916 railway material was being diverted from home to military use. Rolling stock from British railways was sent to France, and the rails themselves were torn up and sent to the western front. The position of the home railways in 1918 became grave. The amount of rolling stock was seriously depleted. Renewal and maintenance work were in arrear. The reserve of track was so low that the companies were not in a position to relay line in the event of any considerable disaster.

III. The Difficulties of 1918.

The most serious problem of this later period of the war was the provision of steel for railway materials at a time when the imports of ore were restricted, and the demand for steel to be used in making other munitions was immense. In particular the steel plates needed for locomotive manufacture could only be obtained by encroaching upon the supplies for ships and tanks. The allocations of material for railway supplies are accordingly discussed in some detail below.[1] Efforts had already been made to ensure the best use of existing supplies and to prevent essential industries from being crippled by speculation in second-hand railway materials. For this purpose the Ministry took control over dealings in these materials in December, 1916. The general policy adopted in regard to the control is described in Chapter V below.

In spite of the difficulties involved in supplying the needs of the British troops overseas without encroaching unduly upon the supply of railway materials for domestic purposes, enormous quantities of rolling stock and rails were provided. The narrative which follows relates only to one side of the nation's activities in this respect, namely, that for which the Ministry of Munitions was responsible.[2] It concerns mainly the supplies for the western front, as a large proportion of the railway material for the eastern theatres of war was provided from India.[3] The supplies which were organised by the Railway Materials Department of the Ministry will be found tabulated in Appendix I. The department provided in all nearly 2,500 locomotives, new and second-hand, over 1,000 new tractors and about 79,500 new and second-hand wagons, in addition to some 7,000 miles of track.

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[1] *See* below, Chap. IV.
[2] The limits of the Ministry's responsibility are defined in Chap. II below.
[3] *See* below, p. 29.

CHAPTER II.

ADMINISTRATIVE ARRANGEMENTS FOR THE SUPPLY OF RAILWAY MATERIAL.

I. British Military Requirements.[1]

Under the War Office, the supply of railway materials for war purposes rested with the Directorate of Transport and Movement within the Department of the Quartermaster-General, orders being placed through a contract section. In August, 1915, the placing of contracts for special plant for rail and inland water transport abroad was undertaken by Section P.M.1 of the Ministry of Munitions, which in the previous June had been transferred bodily from the War Office, where it had been styled Contracts Section 3.[2] This section of the Ministry undertook to place all contracts for railway material, acting as purchasers for the Quartermaster-General. This was merely a matter of convenience, as the War Office retained responsibility for the supply of this store and paid all bills on the orders placed by the Ministry. The War Department preferred to leave the placing of contracts in the experienced hands of the staff which had been transferred rather than to create a new staff under its own jurisdiction. During the early months of the war there was little demand for railway plant, but in the autumn of 1915, when the prospect of an advance was envisaged with the growth in supplies of munitions, it became necessary to arrange for additional railway supplies. Arrangements were made by the War Office in September, 1915, with Messrs. Rendel, Palmer and Tritton, consulting engineers, to act as advisers to the Department on all questions concerning railway plant.[3] At the end of 1915 the Ministry agreed to place contracts for locomotives and railway wagons for the French Government, and in the spring of 1916 there came large demands from Russia. It was, therefore, decided in May, 1916, to establish within the Ministry a Railway Materials Supply Section, in addition to the existing Contracts Section, to deal with demands for railway materials, and, in particular, for locomotives, wagons, and rails, to co-ordinate and develop the manufacturing resources of the country so far as the railway industry was concerned, and to see that demands were fully anticipated.[4] The section was to "focus demands and enlarge sources of supply," placing orders through the Director of Munitions Contracts. Just previously, in March, 1916, the Ministry had suggested that, since the War Office had recently taken back the staff of the

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[1] Hist. Rec./H/500/5, Chap. XV.
[2] Hist. Rec./R/200/2, Part I, p. 24.
[3] Estab. W.P./36/2.
[4] General Office Notice No. 15 (30.5.16).

Contracts Department, which had been responsible for mechanical transport and also for railway materials, that Department should, with the staff, resume its duties of placing contracts for railway material, of which the need was urgent and the supplies hard to obtain.[1] The demands of the Allies, however, altered the situation, and on 29 April the War Office was informed that, in view of the difficulty of separating the purchase of railway materials and rolling stock from the supply of raw materials upon which it was ultimately dependent, the Ministry, in retaining the responsibility for the purchase of railway material, proposed to complete the necessary organisation for co-ordinating and controlling supply.

The new department of the Ministry was subsequently known as the Railway Materials Branch. It was within the department of Mr. (afterwards Sir Charles) Ellis, who had been responsible since the end of 1915 for orders placed on behalf of the French Government. Later it came under the control of Sir Ernest Moir, Bart., who was also responsible for the American Branch of the Ministry. In effect, it dealt mainly with Allied demands, while the Quartermaster-General's Department of the War Office continued to investigate sources of supply for British needs generally, leaving the placing of the contract to the Ministry.

In September, 1916, the results of the Somme campaign were reflected in a greatly increased British railway programme. On 27 September, Sir Eric Geddes, Director-General of Military Railways at the War Office, met Sir Ernest Moir in order to arrange for the assumption by the Ministry of responsibility for the supply of permanent way, rolling stock, locomotives, and heavy plant for the War Office, in accordance with an arrangement between the Secretary of State for War (Mr. Lloyd George) and the Minister of Munitions (Mr. Montagu).[2]

The War Office wished to keep in touch with their consulting engineers on matters of design, and with the Railway Executive Committee, as they were continually obtaining supplies of consumable stores and tools, such as hand tools, etc., through a Stores Sub-Committee of the latter body. It was, however, suggested, in view of the help that the Railway Executive Committee might give both in the manufacture of rolling stock and engines, and in the alteration of second-hand stock, that the Railway Materials Department of the Ministry should conduct all transactions with the Railway War Manufactures Sub-Committee. On 3 October, 1916, the Ministry wrote officially to the War Office[3] undertaking to be responsible for the supply to the Army Council of all locomotives, rolling stock, permanent way, etc., and heavy railway material required by them. The procedure for requisition was to be the same as that established for all other supplies—formal requisition being made to the Department of Munitions Requirements and Statistics. The Ministry undertook responsibility for both design

[1] 94/Gen. No./363.
[2] Estab. W.P./36/2.
[3] *Ibid.*

and supply and for this purpose agreed to employ Messrs. Rendel, Palmer and Tritton as consultants on matters of design and inspection, and Messrs. Mertz and McLellan for electrical stores. No designs were to be altered without the concurrence of the War Office, who were also to continue to deal with the same consultants. The Director-General of Military Railways was to continue to deal directly with the Stores Sub-Committee, and to cease to deal with the War Manufactures Sub-Committee, of the Railway Executive Committee. For convenience, the Ministry staff were to be housed with the staff of the Director-General of Military Railways, but this arrangement was not to be allowed to obscure or affect in any way the distinction between the functions and responsibilities of the Ministry and the War Office. Delivery was to be taken by the War Office at the works or as might otherwise be arranged. The War Office accepted this arrangement on 5 October, 1916, and it worked smoothly until the beginning of 1918, when the question of its application to railway materials for use in Great Britain was raised by orders which the War Office placed with the Railway Executive Committee for a certain number of wagons for conveying tanks and aeroplanes in England.[1] The Director of the Railway Materials Department submitted that while the existing arrangement "might be taken as applying to all rolling stock, etc., required by the Army Council either at home or abroad, the procedure in practice had been limited generally to the supply of railway materials abroad." On the other hand, the member of the Ministry Council concerned stated that "apart from very special requirements, such as ambulance trains, this was the very first case—as far as he was aware—of the War Office setting out to purchase railway material for use in this country."[2]

This divergence of opinion arose out of departmental changes within the War Office. The Department of Military Railways with which the October agreement had been negotiated, and from which alone the Ministry received requisitions, dealt only with overseas requirements. With this department, however, was subsequently amalgamated that of the Director of Movements, who, as being in charge, among other things, of the movement in England over the controlled railways of both stores and troops, had been in direct touch with the Railway Executive Committee and had arranged with them all additional construction services, whether of rolling stock or sidings, to meet military needs in the United Kingdom. There was, in fact, a War Office Sub-Committee of the Railway Executive to deal with this particular question. After the merging of the two departments the Director of Movements had still continued his direct connection with the Railway Executive Committee, and as he was responsible for the transport of tanks in England had ordered the necessary railway wagons.

As the Ministry was placing orders for similar wagons for transport in France, and also for the supply departments at home, it was urged that the War Office action was introducing an element of competition

[1] M.C./629.
[2] *Ibid*, D.M.R.S./434.

between the two Departments. The Ministry accordingly proposed that the War Office should confer direct with the Railway Executive Committee as to the supply of new rolling stock by conversion of old, but that any new construction, together with a statement of the amount of material involved, should be notified to the Railway Materials Department, which would then make the necessary arrangements with the Railway Executive Committee in consultation with the War Office. Acute shortages of both labour and material made it essential that no new construction should be undertaken without the Ministry's assurance that material would be available. Nevertheless, the War Office was unwilling to surrender direct control of construction services undertaken by the controlled railways, in view of its peculiar relations towards them and the financial settlement which would be necessary after the war. The matter was discussed in conference on 24 September, 1918,[1] but no agreement was reached either at the conference or subsequently, and the conclusion of the Armistice with Germany cut short the discussion.

The centre of the question was, in fact, the position of the Railway Executive Committee and the relation of the various departments thereto. The Railway Executive itself was under the Board of Trade, but in all matters of transport of troops and stores it was in very close touch with the War Office. The assumption of responsibility by the Ministry for railway material supply complicated this position by adding a third party to all arrangements. The question then was whether each department should communicate directly with the Railway Executive, or whether the War Office should communicate through the Ministry as regards supply, and, if so, to what extent. The first arrangement was that the War Office should cease to have dealings with the Railway War Manufactures Sub-Committee, which was expected to be of use to the Ministry in its manufacturing programme, but should retain direct touch with the Stores Sub-Committee, which had given valuable assistance with the supply of consumable stores and tools. In December, 1916, however, when it became clear that the manufacturing capacity available to the Railway Materials Department was inadequate to supply the heavy demands from the front, it was necessary to arrange for the release of wagons and locomotives from the British railways. The War Office was anxious that the supply of this second-hand material should be arranged directly between itself and the Railway Executive Committee, and to this Dr. Addison agreed (23 December, 1916), disclaiming, however, all responsibility for supply, transport, or finance under such an arrangement.[2] The War Office was to inform Sir Ernest Moir, within whose general supervision railway material supply lay, of all second-hand supplies arranged through the Railway Executive Committee in order that the Ministry might know the effect both on the transport position and on the total requirements of the Army. All questions affecting rails were purposely excluded from this arrangement in view of their bearing on the general raw materials position. This

[1] M.C./629.
[2] D.M.R.S. 434 and 434 G.

arrangement only affected second-hand material, and any new work to be done by the railway companies for use overseas or on the railways controlled by the Executive Committee was to be arranged by the Ministry. It was laid down in December, 1916, that "as far as new wagons for use overseas and to be built by the Railway Executive Committee are concerned all arrangements are to be made through the Ministry";[1] and that the "new wagons to be built by the Railway Executive include not only those for use overseas, but those to be used on the railways controlled by the Committee."[2] But while the understanding in the Ministry throughout was that "demands on the Railway Executive for all new rolling stock should come through the Ministry," the Director of Movements, of whose activities the Ministry was ignorant, also considered that he had the right, by virtue of his connection with the Railway Executive Committee, to order new rolling stock for military needs at home, and was, in fact, exercising this right, knowing nothing of Ministry arrangements, Moreover, the Director of the Railway Materials Department admitted that, in practice, he had only ordered stores for use overseas.

In fact, the Ministry was entirely responsible for developing trade capacity to meet overseas demands, dealing directly with the Railway Executive Committee in so far as the latter could give any help in manufacture; but this was in practice the limit of its activities in regard to railway material for the British Army.

II. Supplies for the Allies.

The supply of railway material to the Allies had a determining part in the creation of the original supply department and throughout was of considerable importance in its work. The French Government seems at first to have made its own arrangements with British firms, but at the end of 1915, M. Thomas was promised that the Ministry would place certain railway orders to supply military needs. Soon afterwards the representative in England of the French Ministry of Public Works put forward extensive demands for material, and arrangements were then made for regulating demands. The French Government was informed that no requirements for railway material for France would be accepted except through the representatives, either of the Public Works Department or the Ministry of War; while English manufacturers of rolling stock were notified that they were not to accept orders from any quarter except with the sanction of the Ministry.[3] The Russian demands in the spring of 1916 were put forward to the Ministry, and no attempt seems to have been made by the Russian Government to arrange independent supplies in England.

By October, 1916, procedure had been regularised.[4] The orders which were provisionally placed by the delegate of the Allied Government were passed through the Commission Internationale de

[1] M.F./Gen./244.
[2] *Ibid.*
[3] D.D.G.(D) 99.
[4] D.M.R.S. 434.

Ravitaillement to the Ministry with an application for permission to manufacture and export. As they were of all kinds, before they were graded on a war basis by the Department, evidence was needed of their war urgency, without which they were put into Class B or deferred, according to the merits of the case and the material available. As a rule, only requests for material necessary for the actual maintenance of existing railways were granted, but all requests supported by the military authorities were considered. The greater importance of maintaining the goods, as opposed to the passenger service, was also taken into consideration.[1] French orders came directly to the Ministry from the delegate, until, owing to the confusion arising from duplicate demands being received from the Commission Internationale de Ravitaillement, Sir Ernest Moir's suggestion, in April, 1917, that no requests should be received except through the Commission was adopted. The orders then went with the Department's suggested grading to the Railway Priority Committee, where the recommendation was usually accepted, without discussion, except in doubtful cases. The French Government complained early in 1918 of undue delay in dealing with their demands, but on examination it was found that most of the delay was due to the receipt of insufficient information with the first order.[2] It was decided, however, in March, 1918, to form a committee to meet weekly and discuss the orders which the French wished placed in England.

Early in March, 1918, Sir Edmund Wyldbore-Smith suggested to Sir Ernest Moir that there should also be some co-ordination of Belgian demands, which were being satisfied in England, France, and America. As a large part of the material supplied to the Belgians came from England he suggested an inter-departmental centralising committee under the Commission Internationale de Ravitaillement, to scrutinise all Belgian orders, indicating which might best be fulfilled in England and which in America.

This proposal, however, seems to have been merged in general arrangements which were made for fulfilling the railway requirements of all the Allies. On 29 June, 1918, the Commission Internationale announced that a Railway Centralising Committee had been formed to co-ordinate all the supplies needed by the Allies. All orders were to be scrutinised from the point of view of urgency, source of supply, finance, and shipping, and within the scope of the committee came material and machinery and equipment needed in connection with the working of main and secondary railways, light railways and tramways, workshops and power stations.

III. Inter-departmental and Domestic Requirements.

In view of the constructional work on hand for munition factories, and also of the immense munitions traffic, the Ministry itself required considerable quantities of railway material, such as track, for use within factories and for construction of sidings, engines for hauling

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[1] R.M./Gen./98.
[2] *Ibid.*

contractors' material and shunting within works, and wagons for various purposes. These needs could in the majority of cases be met by the use of second-hand material, and as the railway companies frequently had material unfit for main line traffic, this was indicated as the first obvious source of supply. In November, 1916, Ministry departments needing second-hand wagons were instructed to communicate with the Department of Munitions Railway Transport, through whom application could be made to the railway companies for second-hand stores. In no circumstances was application to be made to private firms until the railway companies had been tried without success.[1] This injunction was subsequently modified, to the extent that the Railway Materials Department was made responsible for all negotiations with the railway companies for second-hand stock. Sir Ernest Moir was to be notified by the Railway Executive Committee when any rolling stock or rails were for sale.[2]

Departmental requirements did not, however, end with second-hand stock, and as new stores, such as tanks, aeroplanes, or guns on railway mountings developed, new means of transit were required. The various departments seem generally to have communicated with the Railway Materials Department, but it was not until June, 1918, that a general instruction was issued defining the procedure. All departments in need of new or second-hand material were to pass a requisition to the Department of Munitions Requirements and Statistics, having first obtained financial sanction. At the same time an advance notification could be sent to the Railway Materials Department. The Department of Explosives Supply which had always made its own arrangements for tank wagons was expressly excepted from this procedure.

The question of the central purchase of railway material for all Government Departments was raised in November, 1917. At a meeting, held on 2 November, it was agreed that the Railway Materials Branch of the Ministry should act as a bureau of information as to particulars of locomotives available, and should keep records of engines belonging to the various Departments of State with a view to effecting suitable exchange when found convenient. The War Office and the Office of Works agreed to send all their demands for engines and other railway material to the Ministry.[3]

These demands were met from the stocks of certain smaller locomotive building firms who were allotted a quota of steel by the Controller of Iron and Steel Production, and were allowed by the Priority Department to proceed at their own risk with block orders, from which the demands of the various Government Departments, Government contractors,[4] and important munition contractors, especially steel works, were satisfied. The engines so built were

[1] General Procedure Minute No. 43 (3.11.16).
[2] *Ibid.*, No. 75 (24.2.17).
[3] M.C. 294.
[4] *i.e.*, Contractors employed on the erection of factories or works for any Government Department.

not, however, numerous, and there was considerable competition for them. The Director of Factory Construction, in particular, found his demands curtailed by requisitions from Government Departments. The matter was discussed by all parties interested (15 July, 1918) and it was decided that the Priority Department should allocate no engines from these block orders to private works until it had ascertained from the Railway Materials Department the demands of all Government Offices concerned. In view of the great shortage the various departments undertook to keep their demands as low as possible.[1]

Since railway material was a domestic necessity as well as a military store a special Railways Priority Committee of the Priority Department was established to deal with all orders.[2] Those placed to meet military requisitions took precedence of all others. Orders for the Allies were graded on the recommendation of the Railway Materials Department, but were generally graded lower than British military orders, while every home railway demand automatically received a low (P.5) certificate without reference to the Ministry, and only came before the Priority Committee when higher classification was required. Private orders from contractors to railway manufacturers came straight to the Priority Committee, and it was because it was feared that these orders might compete with urgent war orders that, at the end of 1917, the Director of the Railway Materials Department suggested that all proposed orders for engines or wagons should be passed to him for consideration and report before the Priority Committee took action.[3] He was anxious that all block orders should be kept at the very lowest level, and it was finally agreed that he should be asked for his approval to all suggestions put forward by the Controller of Iron and Steel Production who was specially interested in these block orders.

The general trend of administration was therefore towards centralisation in the hands of the Railway Materials Department. Originally created to provide for War Office overseas requirements, it was also a purchasing department for other branches of the Ministry and for other Government Departments, and finally had asserted its right to be consulted in arrangements touching private industry. This was inevitable with the growing shortage of steel and the consequent necessity for cutting down home requirements to the minimum compatible with that industrial efficiency essential to the satisfactory production of munitions.

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[1] D.M.R.S. 434.
[2] M.C. 506.
[3] M.C. 294.

CHAPTER III.

PROGRAMME AND METHODS OF SUPPLY, 1916–1917.

I. Methods of meeting the Allied Demands, 1916.

(*a*) Supplies for France.

The first Allied demands made on the Ministry itself came from the French Government and were put forward by M. Thomas in December, 1915, to Mr. Lloyd George, who interested himself personally in their satisfaction. They were for 70 "Consolidation" engines and 375 covered wagons, which were intended for the transport of heavy artillery in the military area. Deputy Director-General (D), Mr. (later Sir Charles) Ellis, who was dealing with the matter, suggested that the order should be divided and placed with two of the chief locomotive builders in the country, the North British Locomotive Company and the Vulcan Foundry.[1] The wagon order was placed with the Metropolitan Carriage and Wagon Company, who met it in part from 125 30-ton goods wagons, which had been built for the Argentine or the Central Paraguay Railways. The French State Railways had already placed an order in the summer of 1915 with the North British Locomotive Company for 40 "Pacific" and 60 "Consolidation" engines. This order, however, had been negotiated directly between the French Fives Lille Company and the makers.[2] In accordance with the procedure agreed at the beginning of 1916,[3] M. Leon, the representative of the French Ministry of Public Works in England, put forward on 24 February, 1916, a memorandum on the French demands which included 175 engines, 100 for the State Railways, and 50 for the Paris–Orleans line, and 6,000 wagons, of which 5,000 were for the State Railways and 1,000 for the *Chemins de fer du Midi*, the order from which had already been placed.[4] A proposal to obtain an additional 10,000 wagons in this country was subsequently withdrawn.[5] The memorandum stated that 210 locomotives had been obtained from the British Isles in 1915, and that the French expected to need a similar number in 1916. The various items were the subject of some negotiation and it is not clear whether they were fulfilled *in extenso*. It is certain, however, that an order for 25 engines was placed with Messrs. Kerr Stuart and for 20 with Messrs. Nasmyth Wilson, and during the course of the year (March to July) the North British Locomotive

[1] D.D.G. (D) 99.
[2] 94/L./354. It was originally a direct contract between the State Railways and the Fives Lille Company, who sub-contracted to the North British Locomotive Company.
[3] *See* above, p. 9.
[4] D.D.G. (D) 99.
[5] *Ibid.;* C.R.V./S./335.

Company made further contracts with the French State Railways and the Paris–Orleans Company. In August, 1916, they increased their contract of June, 1915, for 60 "Consolidation" engines to 80 engines, and in September, 1916, contracted for five more.[1] By the end of 1916, therefore, when demands for the British armies were large and urgent, the largest firm of locomotive builders (the North British Locomotive Company) had on their books orders for 260 engines for the French State Railways and 120 for the Paris–Orleans Company.[2] The order with the Vulcan Foundry was placed (15 April, 1916), and specified delivery in 11½ months, but by August, 1917, owing to pressure of Admiralty work on guns and paravanes, delivery had been postponed until June, 1918.[3] The Admiralty orders had been placed with the firm in June, 1915, when locomotive work was slack, and available capacity had then been adapted for gun mountings, breech mechanisms and sights with some difficulty. Some delay had also occurred in the provision of materials for the Ministry order. It was ultimately arranged that the manufacture of locomotives should be continued by the firm with 25 per cent. only of the labour which had formerly been occupied in this work and that the engines were to be completed as soon as possible. The North British Locomotive Company orders were more fortunate. The Director-General of Transportation in France having stated that the delivery of the engines was of importance to the Allies generally, the Ministry did all it could to assist their manufacture, and by the end of 1917 all had been delivered except 50 "Mikado" engines for the Paris–Orleans Railway.[4] It was then decided that any engines built in England should be suitable for use either in England or in France, and as the "Mikado" type did not conform to this ruling and was unsuitable for long distances and difficult to build, the Ministry had not allowed the remaining engines to be built, owing to the steel shortage, and ruled that even if the order should be changed to one for 50 British "Consolidation" engines the material for these must come out of the French steel allocation.

These North British Locomotive Company orders were the subject of considerable negotiation between the French and English Governments, owing to the firm's claim in December, 1916, to be compensated for rises in the cost of labour and material. The Company had made several successive contracts during 1916 without inserting any clause intended to cover rises in cost of production, and its claim was contested by the French. In September, 1917, affairs were so far advanced that the State Railways were willing to compensate for the increased cost of production of 40 "Pacific" and 80 "Consolidation" engines already delivered, but not for any engines yet to be delivered, and the Paris–Orleans Company agreed on the same lines. The French railways complained that they would have placed the orders in America but for the lower prices of the English firm, and it seemed probable that

[1] M.C. 173.
[2] D.M.R.S. 434.
[3] C.R.V./F./023.
[4] D.M.R.S. 439.

the latter in their anxiety to retain the French connection were prepared to face a probable loss.[1]

The Paris–Orleans Company's offer was, however, only contingent on the delivery of the "Mikado" engines, and as the British Government had forbidden this an *impasse* was reached. Various suggestions were made for overcoming the difficulty, one being that the North British Locomotive Company should deliver the engines as and when material became available,[2] but the matter was still under discussion in August, 1918.[3]

(*b*) SUPPLIES FOR RUSSIA.

Russian demands during 1916 were on a comparatively large scale. Negotiations opened in April with a Russian request for a free hand in purchasing British-made rails and rolling stock. Urgent requirements were stated as 240,000 tons of rails and 8,000 wagons, of a total value of $28,000,000, for which negotiations seemed already to have been begun in America.[4] Further demands to the value of £6,000,000 were anticipated. Much stress was laid on the need for track to relay Polish lines as the Russian army advanced. The Ministry replied on 10 May that it was feared that the handing over of unrestricted spending power up to £12,000,000 to the Russians in the United States of America and elsewhere would completely disorganise the railway materials market. The Russian Government had, however, already agreed that the British Government should place all orders in America for Russia through the British commercial agents (Messrs. Morgan). In June, 1916, additional requirements of railway materials were notified,[5] viz : 100,000 tons of rails, 1,300 locomotives, and 35,000 wagons. The total Russian requirement thus stood at 340,000 tons of rails, 1,300 locomotives, and 43,000 wagons. The value of the latest demands was about £27,690,600, and the total value of the demands was nearly £39,000,000. The impossibility of shipping this vast quantity of material was beyond doubt. The Treasury considered that material to the value of £5,000,000 might be shipped, but at that time the credits even for this amount were not available. On 27 June the demands assumed their final form in a memorandum asking for 420,000 tons of rails, 1,300 locomotives, and 35,000 wagons. Of these, the most urgent requirements were 100,000 tons of rails, 500 locomotives, and 7,000 wagons.[6]

It was suggested that the 100,000 tons of rails should be obtained from the United States. Of the locomotives, 100 were to come from the United Kingdom, 100 from Canada, and 300 second-hand from the

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[1] M.C. 173 (Report by Sir Clarendon Hyde).
[2] R.M./Gen./106.
[3] D.M.R.S. 439.
[4] C.R.V./R./05.
[5] *Ibid.* (Treasury to Foreign Office 10.6.16.)
[6] D.D.G. (B) 103.

United States. Canada was also to produce 3,000 wagons, and the United Kingdom 4,000. The estimated cost was as follows :—

		£
Rails—		
U.S.A., 100,000 tons at £9 10*s*.	.. ..	£950,000
Locomotives—		
U.K., 100 at £7,000 each	.. .. ..	700,000
Canada, 100 at £7,000 each	.. .. ..	700,000
U.S.A., 300 at £4,400 each	.. .. ..	1,320,000
	Total ..	£2,720,000
Wagons—		
U.K., 4,000 at £350 each	.. .. ..	1,400,000
Canada, 3,000 at £350 each	.. .. ..	1,050,000
	Total ..	£2,450,000

or a grand total of £6,120,000. It was thought that these arrangements would exhaust the total available capacity of the United Kingdom up to the end of June, 1917, and that the balance of the Russian complete requirements could only be obtained in the United States of America, at a further cost which might be estimated at about £16,000,000.[1]

The Russian requirements were based on the expectation that new strategic lines within Russia would come into operation during the year, and that these would then need rails for their completion and additional rolling stock for their equipment.[2] In the opinion of the Quartermaster-General, the figures of the total requirements were not unreasonable in view of the military situation, but it was undesirable, in view of transport difficulties to Russia, to supply even the minimum requested.[3]

While definite orders in England were awaiting Treasury sanction, Russian agents were obtaining tenders in Canada and America, and the Russian Railway Department was negotiating for 1,300 engines in the United States,[4] but the Treasury disclaimed any responsibility for the finance or shipment of these orders. It was alleged that one of the great difficulties with regard to Russian orders for railway material was that contracts were placed with entirely worthless firms, whom the British purchasing agents would have at once detected, but who

[1] Made up as follows :—

Rails, 320,000 tons at £9 10*s*.	.. .. ..	£3,040,000
Locomotives, 800 at £6,600..	.. .. ..	5,280,000
Wagons, 28,000 at £270	.. ..	7,560,000
		£15,880,000

[2] D.D.G.(B) 103.

[3] C.R. 4502 ; for an account of these difficulties *see* Vol. II, Part VIII, Chap. I.

[4] C.R. 4502.

imposed on the credulity of the Russian Government.[1] Russian representatives had also been negotiating with the Belgian Government, and had obtained from them 150 engines.[2]

Meanwhile the Ministry had been making enquiries as to the possibility of meeting Russian demands in the United Kingdom, and had found that the situation had changed during July, 1916. War Office orders were coming forward faster, and the Admiralty had placed further contracts. Accordingly, it did not seem possible to obtain more than 40 locomotives from England, with delivery from March to 31 August.[3] On 11 August Treasury sanction was given to the following purchases :—

United Kingdom—	£
40 locomotives at £8,000 each	320,000
4,000 wagons at £450 each	1,800,000
Canada—	
60 locomotives at £8,000 each	480,000
3,000 wagons at £400 each	1,200,000
Total ..	£3,800,000

By September, however, it had been decided that no material could be obtained from the British Isles, and it was proposed that all the wagons should be obtained from Canada, and also 20 second-hand locomotives.[4] Negotiations then proceeded with the Treasury as to sanction for American purchases, General Hermonius having asked Treasury approval for the expenditure of £3,800,000 in the United States. The Ministry pointed out that 60 locomotives had already been ordered from Canada through the Imperial Munitions Board, and that the Ministry was committed to an order for 3,000 wagons. Further delays arose from uncertainty as to whether the Treasury sanction was conditional upon the placing of all orders in Canada as for delivery by 30 June, 1917.[5] The question was simplified by the Canadian Locomotive Company's refusing to take the Russian order. Some immediate action was necessary, as the question had been under consideration from April to October 1916, and apparently no rolling stock was being manufactured in either Canada, England, or America. On 31 October the Commission Internationale de Ravitaillement asked the Treasury to transfer the whole credit of £3,800,000 to the United States, which was apparently in accordance with the wishes of the Russian representatives.[6]

Russian orders were discussed at a conference which was held on 27 October at the Ministry in connection with purchases in America of steel for railways. Demands were assumed to be those of June,

[1] C.R.V./R/05.
[2] 121/Railways/122.
[3] D.D.G. (B) 266.
[4] *Ibid.*
[5] *Ibid.*
[6] For negotiations in Canada and the United States and discussion with the Treasury as to Russian orders *see* HIST. REC./H/1142/5, Appendix I.

1916, but the Ministry was in complete ignorance as to the state of supply.[1] Two orders for railway material, however, were placed in Canada, one with the Canadian Car Company for 2,000 wagons and one with the Eastern Car Company for 3,000.[2] Some light was thrown on the position in February, 1917, at a meeting of the Russian Supplies Committee, when the Chairman reported that the orders placed to date in the United States were for 300 locomotives and 3,000 50-ton wagons. These had absorbed the credits of £3,800,000 originally sanctioned by the Treasury. Another order for 500 wagons had just been placed in the States. It was reported that M. Trepoff was negotiating with the Canadian Pacific Railway for the supply of 400 locomotives and 7,000 wagons, to be financed by the Russian Government. It was also understood that Russian orders for rails had been placed in America, amounting in all to 427,773 tons.[3]

II. Supplies for the British Armies in 1916.

(a) Preparations for an Advance in Belgium.

At the end of 1915 the War Office was making arrangements for a possible advance in Belgium. In this event, additional rails would have been required to relay lines destroyed by the enemy. Tenders were issued for 6,000 tons of 75-lb. rails, but only one firm replied, quoting a price about 50 per cent. above the normal. The War Office therefore asked the Ministry (26 November, 1915) to indicate certain firms on whose output it might have first call for about 3,000 tons a week in case of emergency.[4] The Ministry named suitable firms and recommended the War Office to adopt the British standard section rails and instruct the selected firms to prepare the rolls for this section, so that they should be ready in case of need. As points, crossings, and fastenings would take longer to make than the rails themselves, the Ministry suggested that orders for these should be placed in America and a store accumulated.

(b) Miscellaneous Demands for Rolling Stock.

In August, 1916, there were further demands, to raise the stock to 100 miles and allow for current needs. When French demands were being dealt with in March, 1916, there was some fear at the War Office that British requirements would be subordinated to Allied ones, but it was agreed after discussion (March 31, 1916) that forthcoming War Office demands should take precedence of French orders.[5] Tenders were even then being obtained for 60 metre-gauge engines, and a large order for standard-gauge engines was also anticipated. There seems also to have been an urgent requisition for 60-cm. track, 9·5 kilo weight,

[1] Hist. Rec./R/1910/7.
[2] D.D.G. (B) 134.
[3] Minutes of Russian Supplies Committee 1.2.17 and 21.2.17. (C.R. 4503.)
[4] C.R. 2037.
[5] D.D.G. (D) 99/1.

in March, and 45 side-tank engines were ordered from the Hunslet Engine Company for this track, while 30 more were ordered later from the same firm.[1] In October the French offered to release a good deal of this material, but it was useless for British purposes. Demands for wagons were also being put forward—1,000 in March and 5,000 in August. By October orders for 13,000 wagons in all had been placed, of which only 3,000 had been delivered, and their provision was causing considerable anxiety.[2]

(c) THE FIRST WITHDRAWAL OF BRITISH ENGINES.

On 4 June, 1916, a conference on railways was held in Paris to discuss inter-Allied transport questions. Neither the French nor the Belgians were able any longer to provide locomotives for the railways worked by the Railway Operating Division in France.[3] Accordingly, it was desired that 400 engines should be provided from British railways. At the conference this number was reduced to between 70 and 120 locomotives on condition that French orders in England were not diverted. It was also arranged that 200 Belgian engines should be lent, provided that assistance was given in repairing large numbers of locomotives. For this purpose, the British railways were to provide spares for a large number of light repairs and to help in carrying out the heavier work.

The London & North-Western Railway Company agreed to supply the 70 engines which were needed immediately, and the War Office and Railway Executive Committee agreed to press the Ministry to give instructions to Messrs. Beyer & Peacock, locomotive manufacturers, to complete at once 40 partly constructed engines which were being made for the London & North-Western and Great Northern Railways. The Ministry, however, refused to take the firm off their urgent work on gun mountings, and, at the same time (August, 1916), expressed great concern at the effect on munitions traffic of the withdrawal of the 70 engines. In October the War Office asked for the first 20 of the engines from the Railway Executive Committee in order to help the *Chemin de fer du Nord* out of serious difficulties. The replacement of these engines was the subject of considerable discussion. The whole question of withdrawal from British railways was then under consideration, and this small demand was merged in the larger.

Meanwhile the War Office was increasing its contracts for new rails and stock. In August, 1916, requirements were so urgent that orders for 45 side-tank engines had to be placed in America, with the Baldwin Locomotive Company, owing to their superior rate of delivery. It was the increase in British orders during July and August which led to the abandoning of the Russian programme in England. By the time that the Ministry took full charge of British demands, contracts were running for 112 miles of 75-lb. rails and 275 miles of 60-cm.

[1] 94/E./185 and 251.
[2] HIST. REC./R/1910/7.
[3] 121/Railways/122.

(various weights) track; and for a considerable number of engines. It will be seen, therefore, that individual demands had gradually increased in number during the year. In the latter part of the year they were merged in a systematic programme of requirements.

III. Increased Demands, September, 1916, to November, 1917.

(a) Extended Transport Requirements, September–December, 1916.

The new programmes were the result of a systematic survey of transportation problems at the front which was undertaken by Sir Eric Geddes in August and September, 1916. They were chiefly concerned with two classes of railway—the standard-gauge 75-lb. flat-bottom track, and the 60-cm. Decauville light railway.[1] The latter was known as Programme B, and the former as Programme D.

The new feature of the programmes, apart from their enormous increase in size, was the use of the light railway. The development of trench warfare made the means for transporting troops and stores immediately behind the lines of vital importance, especially during periods of intense fighting, when the movement of men to critical positions needed to be conducted with great speed. Railway communications were therefore essential, and for use immediately behind the lines the light railway seemed most suitable. The 75-lb. track (the use of which was urged by the Ministry as against a heavier section of rail) was laid further in the rear. Preliminary notification of Programme B was received at the Ministry on 20 September. On 9 October it was briefly outlined to give some indication of the scale of requirements. The total length of complete track (20-lb.) required, including all curves and sidings, was 1,000 miles. It was to be equipped with 800 steam locomotives, 200 electric locomotives, overhead electric equipment for 200 miles of track,[2] 20 movable power stations, each consisting of one standard-gauge engine and two trucks, 2,800 double bogie trucks, 1 complete equipment for a central repair shop and 50 portable workshop repair equipments for steam engines, and 10 portable workshops for electric engines. The Commander-in-Chief had expressed his urgent desire that the material should be available in the early spring of 1917, provided this were possible without prejudice to the demands already submitted by the Director of Railways (*i.e.*, contracts already placed by the War Office and taken over by the Railway Materials Department), and without lessening the supply of guns and ammunition asked for by him.[3] Preliminary enquiries made by the Director of Movements had elicited the reply from 12 of the chief firms equipped for this work that they could not undertake it owing to the pressure of other military stores, and the Army Council were anxious that a high priority should be given to the material, as otherwise makers might experience great delay in obtaining supplies.

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[1] D.M.R.S. 434 and Hist. Rec./R/1910/2.
[2] This demand was not persisted in and supply was not arranged.
[3] D.M.R.S. 434.

The standard-gauge programme was not put forward until the end of November.[1] It was for 1,200 miles of 75-lb. (or 80-lb.) track, (flat-bottomed), 300 new large main-line locomotives, and about 9,000 wagons. Power stations and repair shops were also asked for. In addition, there were various military requirements for which supply was being arranged, when the Ministry department was formed. These constituted "Programme A," which was chiefly for various narrow-gauge stores, tracks, and engines, either steam or electric, and for standard-gauge goods wagons of various kinds. Programme C comprised miscellaneous demands, including 80 miles of second-hand 80-lb. rails from America, and a considerable amount of 75-lb. track for the East—Salonika and Mesopotamia—50 miles of metre-gauge track, and 40 miles of 60-cm.-gauge track.

The need for these railway materials was extremely pressing. On 26 September the Commander-in-Chief represented that much depended on the speed used in developing the programme for rail and rolling stock. On 7 October he telegraphed that—

> "Supplies of rail and rolling stock are most urgently required and I cannot bring too strongly to the notice of the Army Council the need for railway plant and rolling stock generally. It is essential if the supplies of munitions are to reach the troops that demands already sent forward should be met in full at the earliest possible date. As the autumn advances and the weather becomes worse the necessity for railway equipment will become greater and will have a considerable effect on operations. The increasing quantity of stores and munitions now asked for necessitates a correlative increase in my transportation services and, while the supply of guns and gun ammunition must take precedence, I consider the supply of railway material and rolling stock to be of almost equal importance."[2]

Finally, at the beginning of December, Sir Douglas Haig paid "a personal visit to the country for the purpose of impressing on all concerned the extreme importance to his operations of carrying out the proposed programme."[3] On 12 December he wrote a long account of his needs. "It is clear that large schemes for doubling and building certain lines of railway should be taken in hand at once, as also the construction of new connecting lines, extension of regulating stations, construction of new depôts in the rear, and considerable extensions of railways in the army area."[4] He asked, therefore, for 300 miles at once, and a continued monthly delivery of 150 miles. Stock at that moment was less than 50 miles and was causing great anxiety, and he could not insist too strongly on the urgency of improved deliveries of 75-lb. broad-gauge rails. Although it was both inconvenient and uneconomical to have mixed descriptions of track, nevertheless rails must be forthcoming, and if the standard track could not be supplied

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[1] HIST. REC./R/1910/1 and 2.
[2] D.M.R.S. 434.
[3] *Ibid.*
[4] *Ibid.*

the Director of Railways in France would accept the best substitute. He then reviewed the position of supply of various stores. The supply of broad-gauge wagons was in arrears and substantial deliveries were not anticipated until the late months of the first half of 1917. The shortage in France was very serious and owing to this the advantage of considerable quantities of material was being lost. As the railway companies were the only source of supply he asked the Army Council to do all in its power to get second-hand wagons out at once. The locomotive position was equally serious—there was no time to obtain engines for the spring offensive, while the French had made demands for assistance amounting to between 400 and 500 locomotives for main line working, in addition to shunting engines being built in America. Here, again, he urged that the British railways should step into the breach. The construction of 60-cm. track was also important if the best use was to be made of the man power in France; forecasted deliveries should, if possible, be improved on. In addition to the large works mentioned at the beginning of his letter, the operation of certain sections of the French railways would undoubtedly have to be undertaken, and for this reason he reiterated his demand for as many stores as possible as soon as possible.

In addition to these programmes for tracks, wagons, and locomotives, there were many demands for the most miscellaneous accessory stores —such as machine tools for workshops and power stations, as well as repair trains and portable power stations themselves; cranes, pumps, storage tanks, and piping for water supply. Former programmes had included all the necessary accessories such as points and crossings, all the different fastenings, and spare wheels for wagons. The wagons demanded, in addition to being of various gauges, were of many different sorts, open and covered, and of varying capacity. Requisitions for spares of all sorts were frequent.

(b) Sources of Supply.

Meanwhile the organisation of supply was no light matter, owing to the preoccupation of railway firms with other work. In the slack period of 1915, when orders were not forthcoming, locomotive builders especially had taken on shell and gun work and could not in 1916 be released. The largest of these firms, the North British Locomotive Company, was completely engaged upon French orders; the Vulcan Foundry could not even finish its French orders, owing to Admiralty work; Messrs. Beyer & Peacock were manufacturing guns and could not fulfil their existing orders with the railway companies.[1] Messrs. Robert Stephenson had only small capacity, some of which was on munition work proper; Messrs. Kitson were making gun accessories.[2] The smaller of the railway firms, and those capable of building smaller engines, were thus alone able to take British railway orders. Their efficiency was poor, and according to one critic they were a "helpless,

[1] R.M./L/121 and M.C. 560.
[2] R.M./Gen./51.

hopeless crowd," always in financial distress and with a "puerile output."[1] The American curves of output were infinitely superior to the British. Part of the trouble was due to the lack of standardisation, for which the railway companies were entirely responsible. Each company had its own ideas as to what constituted a good engine, and one company alone had 33 different types. When it came to bulk production, therefore, the locomotive firms were handicapped, and in any case their capacity was far inferior to that of the American firms.

As a result, extensive orders were placed in America with the Baldwin Locomotive Company. One contract alone was for 450 60-cm. engines, and in all 725 engines were ordered in America, excluding the 45 under Programme A, while 40 came from Canada. Excluding orders for 130 already placed, only 95 were ordered in the British Isles to meet the new programmes at the end of 1916.[2] This action was bitterly criticised by the Locomotive Manufacturers' Parliamentary Association;[3] but it was inevitable, as speedy delivery was the first essential, and this the British firms were totally incapable of giving. For instance, the terms of delivery of the Baldwin Locomotive Company's contract for 450 side-tank 60-cm.-gauge engines, placed in October, were for delivery at the rate of 25 a week, beginning early in December, 1916, and ending 15 April, 1917. Similarly, the order for 50 shunting engines, placed with the same firm in December, was for delivery of one a day, beginning on 31 January, 1917. The only other American firm with whom orders were placed was the American Locomotive Sales Corporation, from whom 100 60-cm. side-tank locomotives were ordered for delivery during the first three months of 1917. Practically no orders were, however, placed out of England for the tractors, either petrol or petrol-electric. The latter were an innovation, and orders for the 200 requisitioned by the War Office were evenly distributed between Messrs. Dick, Kerr and Nasmyth Wilson. No further orders were received for this type, the War Office preferring to concentrate on the ordinary petrol type. The supply of engines was for a time a difficulty, owing to competing demands of other stores, but finally it was arranged that the Mechanical Transport Department should allocate a certain number every month for the Railway Materials Department's purposes. There was also difficulty with Messrs. Thornycroft's orders owing to competition with Admiralty orders, which were delaying the tractors very considerably.

As regards rails the position was somewhat different. There were many English firms capable of rolling 75-lb. flat-bottomed rails, and the main problem was the allocation of the output of the rolling mills, a matter controlled by the Steel Production Department of the Ministry. The 1,200 mile standard-gauge programme alone meant the supply of 160,000 tons of steel, or 6,000 tons a week for six months,[4] and the

[1] A.C. 39.
[2] HIST. REC./R/1910/2 and R.M./Gen./56.
[3] HIST. REC./R/1910/1.
[4] C.R. 4480.

1,000 mile narrow-gauge track implied 60,000 tons for rails and sleepers, even when requirements had been reduced by the adoption of a lighter sleeper.[1] As shell discard was used for making 60-cm. rails, the problem became one of rolling mill capacity and not materials for the rails themselves. It was finally agreed that the shell programme should not be disturbed if it could possibly be avoided. An order for 1,500 tons a week to be rolled by the Dowlais works for the home railways was to be taken over for overseas requirements, and Messrs. Bolckow, Vaughan were to produce 500 tons of rails in place of shell steel for the French Government. The home railways were to be further denuded by withdrawing 1,200 tons of rail steel a week up to a total of 30,000 tons, to be rolled by the London and North-Western Railway works for military railways instead of for home requirements.[2] Attempts were also made to obtain rails or steel from India, Australia, and Canada.

The 60-cm. track was in a special category, in that the section was a new one, and some difficulty was experienced in making the necessary machinery for manufacturing the rails.[3] In any case no attempt was made to go beyond the British Isles for sources of supply; but one or two foreign contracts were placed for the heavy rails. The only American order was for 80 miles of 80-lb. flat-bottomed second-hand rails from the Wellsville & Buffalo Railroad Corporation.[4] Supplies of new rails were also obtained from India[5] and Australia[6] for use in the East, and second-hand rails were obtained from Canada.[7] As regards the latter, a cable was sent out at the beginning of December, enquiring whether there was any possibility of securing rails in Canada, and the Imperial Munitions Board replied that it seemed probable that several hundred miles of second-hand 75-lb. rails could be secured. They suggested that an appeal should be made through the Governor-General to the Dominion Government which might be cited if trouble arose through the tearing up of the rails. On 17 December the Canadian Minister of Railways was instructed to tear up 300 miles of 80-lb. rails, and the Imperial Munitions Board took up the question with enthusiasm, cabling as follows: "All heartily co-operating and we are confident that 1,000 miles of track will be available. Hundreds of miles of light 20–30 lb. rails available, also locomotives and cars to run on the tracks." The Ministry, however, proceeded cautiously, making full enquiries as to the rails, and on 20 December cabled that they would accept 300 miles of 80-lb. rails, provided they were all of one section and in thoroughly good order, complete with fastenings and other accessories.

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[1] Hist. Rec./R/1910/7.
[2] C.R. 4480.
[3] D.M.R.S. 434.
[4] R.M./Gen./56.
[5] *See* below, p. 28. Rails from India, in actuality, never went to France.
[6] 165 miles were ordered in Australia, of which 40 were rolled, but this order was later cancelled, owing to lack of tonnage induced by the necessity of shipping food. (D.M.R.S. 434 K.)
[7] C.R. 4480. (Copies of I.M.B. telegrams.)

Finally, as regards wagons no foreign contracts at all were placed. Large orders were placed with the standard English builders, but here, again, there was trouble, because the firms were already engaged upon other munition work. The Metropolitan Carriage & Wagon & Finance Company, for example, held by far the largest contracts for building tanks, and from the beginning of 1916 onwards their capacity was more and more absorbed by mechanical warfare contracts. The railway companies, however, undertook a contract for 2,500 20-ton covered goods wagons, which had been designed by them jointly with the Ministry. But the supplies outlined above were not forthcoming immediately, while Sir Douglas Haig's requirements were of the most pressing nature. In the emergency, therefore, application to the railway companies became absolutely necessary. By arrangement between the Railway Executive Committee, the War Office, and the Ministry 200 miles of track were to be taken up at once in out-of-the-way parts of the country for shipment to France. At the same time the gradual release of 11,000 wagons, to begin at once, was arranged, and the negotiations for the transfer of 70 London & North-Western engines to France were merged in the larger demands owing to the Commander-in-Chief's programme. In all 370 locomotives were to be sent abroad.[1]

On 5 January, 1917, the War Office was notified of the Ministry's arrangements for supply. As regards rails, rolling was going on in England at the rate of 10 miles a day, and second-hand supplies were being obtained from the British railways, Canada, and America. The supply of wagons was retarded by press of other urgent work. The forecasts as regards narrow-gauge track could not be maintained owing to difficulties in manufacture. Deliveries at the end of April were not expected to exceed 700 miles, of which not more than 200 would be complete by the end of January. It was hoped to maintain forecasts of the delivery of 60-cm. rolling stock.

(c) DELIVERIES.

By March 10, however, deliveries were, on the whole, in excess of promises, as appears from the following table :—

Position of Railway Material Supplies, March, 1917.

	Total Produced.	Total Promised.	Total awaiting Shipment.
Rails, 20-lb.	418	350	278
,, 75-lb. and 80-lb.	652	375	405
Wagons, standard	8,469	5,233	1,222
,, 60-cm.	862	1,753	336
Locomotives, 60-cm.	407	245	109
,, standard	—	None due	—
,, shunting	50	50	40

[1] D.M.R.S. 434.

It will be seen that the supplies awaiting shipment were considerable. They included 50 miles of track from Australia, 107 miles from Canada, 86 miles of second-hand British track and 115 miles of new, while 149 engines were held up in America.[1]

Deliveries during the spring of 1917 were not up to forecast, especially on the 60-cm. programme, but by June, 1917, the various track programmes were well up to date. The 1,000 miles of 60-cm. track were complete, but the other smaller requisitions were not quite up to forecast. The standard-gauge programme was only retarded by the failure of the shipment of American and Canadian supplies. Of the 80 miles from America only 32 were shipped and only 183 out of 300 from Canada. The programme was for delivery from February to September (*i.e.*, to be complete by 1 October), but with adequate American and Canadian deliveries it was expected to be complete by the middle of August. Wagon contracts were nearly up to forecast. Out of 20,778 standard-gauge wagons requisitioned up to date, delivery of 8,794 was expected, while actually 8,417 were delivered, and 60-cm. stock was equally well up to time.[2]

The deliveries on the American locomotive contracts were remarkably good on the whole. The order for 450 engines was not complete until some months after it should have been, but this was due to the extreme congestion on the American railways, whereby the material was hung up at the manufacturers' works. It should be noted that one of the terms of the American contracts was that the buyer might at his option refuse to take all, or to pay for all, engines not completely manufactured and ready for final inspection by the date mentioned in the contract, except such as were delayed by circumstances over which the company had no control.[3]

The delays in shipment were, however, so acute, that by May, 1917, 10 only of the 50 Baldwin engines completely manufactured and due in March, 1917, had been shipped, and this in spite of their being urgently needed in France. Again, in August, 1917, of 325 locomotives ordered 140 had been delivered, but only 40 had been shipped. The importance of these deliveries could not be overrated. "There had never been," wrote Lord Derby, then Secretary of State, "nor was there at that time any more crying need of the armies in France than the supply of locomotives," and if the supply failed the British Government would have to break its understanding with the French. Under the contracts placed in December, 1916, and January, 1917, 175 locomotives were on order, the last of which were to be complete by 7 September. They were completed up to date,[4] but only 74 had been shipped. It was not until the middle of November that they had all been despatched, and by then deliveries under new contracts were competing for tonnage.

[1] C.R.V./Gen./0255.
[2] HIST. REC./R/1910/2.
[3] 121/Railways/122.
[4] (Printed) *Weekly Report*, No. 108, V (8.9.17).

(*d*) Later Additions to the Programme.

Meantime, the requirement continued to increase. In May, 1917, a demand for 1,000 miles more of standard-gauge track was put forward for delivery from July onwards.[1] Of this, 300 miles was to come from Canada in the form of 80-lb. second-hand rails as soon as the first 300 miles had been shipped, and 380 miles were arranged for in the United Kingdom for delivery up to the end of the year. It was impracticable to draw further supplies from Canada, by reason of exchange difficulties. The balance of 320 miles could not, therefore, be met save by reducing the steel allotted to the shell programme, and at the desire of the Commander-in-Chief, delivery of the balance of rails was postponed till the early months of 1918, in preference to interfering with shell manufacture.[2] There were also demands for additional locomotives: 100 "Consolidation" engines were ordered in England and 100 in America, and 50 shunting engines also in America. A demand for 900 more miles of 60-cm. track was also put forward, for delivery from July to December, 1917.[3]

By the beginning of December there were in France 704 main line locomotives, of which a large proportion had been provided by the British railways. This was a better result than the Director-General of Military Railways had expected. One of the difficulties which occurred at this time, and intermittently during 1918, was the difficulty of getting programmes of work settled sufficiently far in advance to allow of firms passing from one order to another without any break. It was essential to keep railway capacity open in case of urgent requisitions. This lack of an advanced programme occasionally gave rise to delay in manufacture, as, for instance, occurred in the spring of 1918.

During this period the Railway Materials Department was striving to obtain high priority for its orders, and also to win back railway capacity from other munitions work. The Vulcan Foundry was engaged upon Admiralty orders, for which it was not found possible to substitute railway work. Messrs. Kitson, of Leeds, had orders for both locomotives and tanks. It was decided that the tank order should first be finished and that the firm's capacity should then be freed for railway materials.[4] The preoccupation of wagon-building firms may be judged from the fact that the normal yearly output of 52,000 wagons had declined to about 18,000 or 20,000.[5] Deliveries on the track orders were fairly good, estimates being more than realised on the 60-cm.-gauge programme, but not quite realised on the standard-gauge. British output of locomotives was also up to time, while deliveries on the American orders were good. Although none of the "Consolidation"

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[1] D.M.R.S. 434 K.
[2] *Ibid.*
[3] Known as Programme E; first for 400 and then for some 500 more miles.
[4] D.M.R.S. 434.
[5] R.M./Gen./36.

engines were due until 15 December, 1917, 81 had left the works by 14 December.[1]

The Department had its own production engineers (21 in all), whose sole duty it was to hasten production. They visited the various railway material firms, saw that they had sufficient material to keep them going, and generally took steps to see that no avoidable difficulties should be allowed to stand in the way of output.[2]

The priority given to railway material during the year 1917 was very good and accounted in part for the satisfactory deliveries. In February, railway contracts came third in order of urgency, being subordinate only to guns and tanks, and in March they ranked fourth, aircraft requirements being given first priority. Until November, nearly all railway stores were in Group I, only the 60-cm. track and accessories and metre-gauge stores being in Group II. In November, however, supplies were so far satisfactory that railway materials were placed sixth in order of urgency. The chief stores in Group I were standard-gauge locomotives, petrol tractors, and spares, machinery of various kinds for repairs, and signalling material. The problem of 1918 was not one of capacity, but of steel supply.[3]

IV. Egyptian Railways.[4]

The railway shops of India, equally with those of Great Britain, had been engaged in the earlier stages of the war upon munition manufacture, and particularly shell production.[5] The abandonment of Indian H.E. shell manufacture in the autumn of 1916 set free additional capacity, particularly that of the Tata Iron and Steel Company, which was also providing railway materials for Mesopotamia. It was accordingly decided to seek help from India in meeting the heavy demands for military railways in France, and on 29 November, 1916, the India Office was asked whether 20,000 tons of 75-lb. flat-bottomed, British-standard section steel rails could be supplied by Messrs. Tata for this purpose. The Indian Government was informed that the demand was most urgent and took precedence of all civil demands. A reply was received that there were in stock about 22 miles, and that Messrs. Tata's monthly output was about 46½ miles. The Commander-in-Chief, Mesopotamia, had asked for 20 miles of 75-lb. rails a month, and the Indian Government wished to know whether supply for France was to over-ride this demand; if so, the supply to France would be about 6,000 tons a month.

The War Office here intervened, giving instructions (14 December, 1916) that the rails in stock should be sent to Egypt to meet urgent requirements, and that supply should be to Mesopotamia at the rate of

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[1] R.M./Gen./56.
[2] M.E./H/331.
[3] *See* below, p. 31.
[4] D.S.P./15, 28 and 63.
[5] *See* Vol. II, Part V, pp. 5–12.

20 miles a month as asked for. On 20 December these decisions were communicated to the India Office, with the explanation that the Army Council thought it best to utilise the resources of India in the first place to meet urgent demands in the Mediterranean, for which rails would otherwise have to be sent from the British Isles. A further 26 miles would be needed for Egypt after the first 20 had gone to Mesopotamia. The Ministry was in opposition to the use of these supplies in other theatres of war than France, contending that it had been definitely agreed at the end of 1916 that Indian supplies should eke out home production to meet the demands for the western front. Although supplies for France necessarily suffered thereby, the Army Council maintained its policy on the ground that the shipment of track from India to Egypt without submarine risk would, in case of need, justify the use of 75-lb. rails instead of the second-hand track that had been obtained from other sources. In January, 1917, the Indian Government cabled that the Railway Board had decided to adopt lighter rails than the 75-lb. for Mesopotamia, as they had come to the conclusion that no more than a metre-gauge railway would be needed in that country in view of the possibilities of water transport. The 75-lb. rails, which had been adopted with a view to their being used when the gauge should be broadened to the standard, would be no longer necessary. Stocks of lighter rails—65 miles in all—were available in Mesopotamia and 33 miles of 50-lb. rails could come from East Africa. The Director of Railways, Basrah, had therefore agreed to accept a lighter section rail. This would set free greater quantities for Ministry needs, and after February it was expected that the whole of the Tata Company's output, save 500 tons needed for Ishapur, should come to the Ministry in the form most desired, either as shell or rail steel. After considerable discussion as to the type of rail, whether of British or Indian pattern, it was agreed by the War Office (21 February, 1917) that the whole of the 20,000-ton order should be rolled with Indian fish-plates, as Messrs. Tata could not have the British standard section rolls complete before April, when the order should be complete. Practically the whole of the order was sent to Egypt, where there would not be so great confusion as in France through having two types of rail.

On 13 April, 1917, the Commander-in-Chief, India, had instructed Messrs. Tata to roll alternately for two weeks each, 75-lb. rails for Egypt and 41½-lb. rails for Mesopotamia. On 17 April the War Office wired to the Commander-in-Chief asking that all possible steps, including working of overtime, should be taken to hasten the delivery of the balance of the 20,000-ton order, in all 51 miles, for Egypt, in order not to suspend operations there, and to enable Egypt to return borrowed track to Salonika and yet maintain a stock in reserve. As English output was entirely absorbed in supplying rails for France, India thus became the sole source of supply for Egypt and Salonika.

On 23 April, 1917, the Ministry asked the India Office to arrange, if possible, for Messrs. Tata to accept a contract for 24,000 tons more steel rails at 5,500 tons a month. This rate of output could not, however, be promised owing to Mesopotamian demands, but the following output was estimated—3,000 tons in May, 3,500 in June, 5,300 in July,

5,300 in August, and so on monthly until the order was complete. Monthly shipments were to begin in June. In September, 1917, the Ministry asked for another 7,000 tons, which Messrs. Tata expected to be able to supply by the end of October. A large railway extension programme in Egypt was then under contemplation, the first part of which alone involved 250–280 miles. To meet this, 114 miles had by 1 August been shipped from India on the 24,000-ton order (roughly 205 miles), and in addition to the balance of the order an additional tonnage of about 50 miles was needed. On 20 October, 1917, the Ministry asked the India Office to instruct Messrs. Tata to continue rolling rails at the same rate as before, until further notice, until a specific requisition could be made. On 28 January, 1918, arrangements were made for a covering order for roughly 200 miles of rails to be placed with Messrs. Tata, which should include the 40 miles rolled and shipped to Salonika under the general instructions given in October. The remaining 80 miles were intended for Egypt, and were to be complete by February, 1918.

CHAPTER IV.

THE SPECIAL DIFFICULTIES OF 1918.

The position in 1918 became exceedingly grave, both by reason of the general shortage of steel, upon which railways were entirely dependent, and because by that date home railways were suffering seriously as the result of extraordinarily heavy traffic, difficulties in regard to renewal and maintenance, and the withdrawal of rails and rolling stock.

I. Steel Allocation.

(*a*) EFFECTS OF THE SHORTAGE OF STEEL IN 1918.[1]

On 15 February, 1918, the Ministry notified the Army Council that it was proposed to allocate 72,000 tons of steel for railway requirements for the whole of 1918. The outstanding demands indeed amounted to 126,500 tons of steel, but of this 37,000 tons was for the 75-lb. track, the demand for which was in abeyance. There remained, therefore, a requirement of 89,500 tons (February to December), which it was hoped the Army Council would reduce to 72,000 tons. The quantity of steel available for War Office purposes could be allocated in various ways, and the Ministry hoped that the War Office would consider the allocation of steel as a whole. In reply, the War Office stated that its irreducible minimum for overseas railways was 173,000 tons.

The amount of 72,000 tons, proposed to be allocated, not only did not allow steel for any new demands which might be put forward in the course of 1918, but even necessitated a reduction of 18,000 tons (inclusive of the 37,000 tons for 75-lb. track) on the demands already outstanding on 1 February, 1918. The demand for 75-lb. track, however, was not abrogated, but only in abeyance for two months, and although, owing to the satisfactory stocks in France, this might be extended, causes might arise making the fulfilment of the demand imperative. The further reduction of 31,000 was considered quite impracticable, as it would touch the supply of light rails, broad-gauge wagons, and engines, all of which were already on order and urgently needed. There were also new programmes in view. One for wagons up to September, 1918, involving 13,000 tons of steel, had already been put forward, and further considerable orders would be absolutely essential, .which even under a policy of drastic reduction it would not be safe to put at less than 20,000 tons. If the policy were one of extension, that figure might have to be largely increased. Attention was drawn to a report from Sir Philip Nash on transportation at the front, stating that a " large increase in wagons and possibly engines

[1] D.M.R.S. 434.

was one of the most pressing necessities." The following table illustrates the position in regard to railway steel at this date (February, 1918):—

Steel for Railway Purposes.	*Tons.*
Deliveries in January, 1918	13,500
Outstanding requirements, 1 February, 1918	126,500
Wagon programme to 30 September, 1918	13,000
Provision for further requirements.. ..	20,000
	173,000

Shortly afterwards the War Office found it necessary to requisition 100 locomotives, and proposed that while the material could be taken from the 20,000 tons allotted for further requirements, it would be preferable that so large a quantity, viz., 9,000 tons, should not be taken out for one demand. This demand raised the question whether railway materials were to have priority over the munitions of war, which were dependent upon the allocation of steel. On 23 April the Army Council represented that the provision of steel for overseas railways had always been treated as an entirely separate question from that of other War Office demands, and the increase of the railway allocation should not affect other demands. They added:—

> "The events in France during the last few weeks and the serious losses incurred in materials of all kinds not only make it impossible for the Council further to reduce the Army demand for engineer stores, mechanical transport, etc., requiring steel, but it will necessitate a revised allocation of steel amongst all departments owing to the altered conditions."

The Ministry, on the other hand, pointed out that it would be impossible in future to treat railway materials apart from other manufacturing programmes. There was, moreover, a settled belief that there were large stocks of railway material in France, and that the limited material and manufacturing capacity at home could be better employed on stores of which there were not large stocks. In particular, the First Lord of the Admiralty (Sir Eric Geddes), judging by intimate knowledge of transport conditions which he had gained in France during 1916–1917, considered that the demands of merchant shipbuilding might safely take precedence of railway material. Accordingly, requirements for railway material were held up in the Ministry from 12 April onwards, pending a settlement of the exact allocation of steel. During that month events in France altered the general position. On 24 May it was agreed that, the demand for 75-lb. track excepted, all suspended requisitions were to be released on the understanding that the necessary allocation of steel should be made for the next three months. The steel required for the rest of the programme was to be considered later. The June to December requirement was estimated at 106,400 tons, and if the 75-lb. track were added, at 143,400 tons. In June, 1918, the War Office gave an account of the position at that date. Great strain was being thrown on the resources of the

western front in locomotives and rolling stock by the increase in the American Army, considerably in advance of its transport, and by the growing necessity of saving sea transport by rail transport to the Mediterranean, especially for reinforcements for the East and coal for Italy.[1] Recent operations had led to grave shortage of rolling stock for the requirements of the British Army, and might necessitate exceptional measures being taken to afford temporary relief. The rolling stock situation as a whole had been considered by the Allies, and the British contribution had been fixed at the moderate figure of 100 engines and 5,250 wagons. The losses during the retreat had amounted to over 750 miles of light railway track, 189 locomotives, 138 tractors, and 1,885 wagons.

On 14 June the Army Council was notified that instructions had been given to proceed with the manufacture of the 75-lb. rails at the rate of 10,000 tons a month and that the delivery would be complete in October. Still more of these rails were, however, required in August, as the expenditure had been heavy and was expected to continue so for some time. Stocks in England and France on 10 August had only amounted to 373 miles. On the basis of the existing arrangements, which ended on 31 October, the estimated deliveries were 337 miles. As there was an authorised laying programme of 25 miles a week, which by the end of October would have absorbed 300 miles, the stock of rails would be reduced to 310 miles. The Army Council considered that the irreducible minimum of stock which ought to be held for France should not be below 400 miles, and that a stock of 50 miles should also be held in England. They asked, therefore, for 140 miles extra by October.

Orders were placed for the extra demand, but while on the one hand estimated deliveries did not come in, on the other the laying programme had absorbed 40 miles a week, and the minimum stock to be held was raised to 500 tons, so that the War Office asked that the weekly rolling of 6,000 tons arranged for September and October should be continued until stock had been built up. Three 18-pdr. shell factories had already been closed owing to urgent rail orders, which meant the diversion of the rolling mills from shell steel.[2] In November, 1918, owing to the reduction of the shell programme for 1919, even more capacity was allocated and it was arranged to roll railway steel at the rate of 7,000 tons a week.[3]

(*b*) PROSPECTIVE ALLOCATION FOR 1919.

The 1919 programme is of interest, as it shows the importance which railway supplies had assumed with the changed conditions of warfare during 1918.[4] The prospect of lengthened lines of communications made imperative a large heavy-rail programme. The original

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[1] In August the shortage of wagons was so pronounced that railway companies were providing another 10,000, chiefly for coal traffic to Italy. (D.M.R.S. 434.)

[2] Minutes of 81st Meeting of Co-ordinating Committee, 8.9.18. (HIST. REC./R/1000/61.)

[3] To meet a demand for 600 more miles of railway by March, 1919.

[4] Minutes of Co-ordinating Committee. (HIST. REC./R/1000/61.)

allocation for 1919 for home and overseas railways was to remain at 500,000 tons, but whereas the former in 1918 had received 230,000 tons, they were now to get 170,000, and the latter 330,000 instead of 270,000 tons. In October, 1918, however, the total allocation was cut down to 450,000 tons, and as overseas demands had risen to 415,000, only 35,000 were left for home railways. By November, demands stood at 626,000 tons, of which 346,250 was allocated to overseas railways, the requirements of which had been greatly reduced already and could not be further reduced. In particular, arrangements for the prospective need for heavy rails and engines in the event of an advance to the German frontier, and arrangements for relaying the Belgian main lines with 93-lb. rails, were essential.

The first 1919 locomotive programme was for 220 locomotives, of which 60 were to go to India to meet urgent military needs, but when the Ministry was informed that many more than 160 engines would be needed for France, it was decided that the Indian requirement could only be met in America, and, accordingly, negotiations were entered into with the Baldwin Locomotive Company.[1] In October the requirements for France were put at 25 engines a month,[2] and indications were received of colonial requirements amounting to about 218 engines.[3] The cessation of hostilities put an end to the negotiations for American engines for India, the order for which was placed in England; while colonial orders were also welcomed to provide transition work for railway firms.

II. Standardisation of Locomotive Production.

One of the main features of the 1918 programme for locomotive manufacture was an attempt made by the Ministry to adopt standard types and concentrate upon their production rather than to manufacture numbers of different types. One of the evils of the English system had been its great variety of types, and it was hoped by this action to put the trade into a position to cope with foreign competition after the war. After some discussion the two types fixed upon were the "Consolidation" 2-8-0 type (designed by the Great Central Railway) for mineral traffic and the new 2-6-0 designed by the Chief Mechanical Engineer of the South-Eastern and Chatham Railways for mixed goods and slow passenger traffic.[4] The suggestion was to build to these two types whenever steel was available, for use either in France or by the railway companies, and so keep the locomotive builders, whose orders were expiring, engaged on their proper manufacture. The Minister had agreed in November, 1917, that 150 "Consolidation" engines should be built as and when steel became available, and the Director of the Railway Materials Department suggested that the orders should be allotted to the North British Locomotive Company, Messrs. Stevenson,

[1] C.R.V./Gen./0386.
[2] D.M.R.S.434.L.
[3] Minutes of 97th Meeting of Co-ordinating Committee. (Hist. Rec. /R/1000/61.)
[4] R.M./E/5.

and Messrs. Kitson, according to capacity, *i.e.*, 100, 25 and 25 respectively. While steel supply was the crucial point, it was imperative that the locomotive firms should be kept continuously at work when their existing orders were complete by June, 1918. Any serious break in production necessarily resulted in the dispersal of specialised labour. The Railway Executive Committee were not entirely in favour of the scheme, as they considered that material, of which there was such an acute shortage, would be diverted to new manufacture which would more usefully be employed in repairing the large number of engines out of order. It was just as easy for railway contract shops to organise for repair as for railway companies' shops to organise for the manufacture of munitions. The railway shops were still being pressed to manufacture munitions, whereas, the Committee argued, "it would appear that less disturbance would be caused to the production of the country by locomotive contract shops undertaking munition work, leaving the railway shops to carry on their normal occupation." Both the railway companies and the Ministry were anxious to enable the trade to prepare for peace by so organising the shops as to enable them to be readily converted to peace-time production.

In January, 1918, small orders were placed to keep the shops at work, and a proposal was made to build 17 engines a month for three months, nine with the North British Locomotive Company, and the rest with the smaller firms. Considerable difficulties were experienced in obtaining allocations of steel for these orders, owing to Ministerial instructions that the priority of tanks over locomotives should be absolute. In March, 1918, the scheme for keeping railway shops fully occupied upon locomotive orders was reconsidered and approved in view of a surplus of steel which then existed by reason of the non-fulfilment of Admiralty and tank programmes. The War Office at once put forward a demand for 100 locomotives. In August, 1918, the position in regard to locomotive manufacture was again serious, both because of the large proportion of the productive capacity of the more important makers which was absorbed on tanks and other munitions, and because of the absence of a definite programme of manufacture for 1919. It was proposed by the Director of the Department that the Indian demand for 100 engines and any War Office demands should be met by orders in England to keep the firms busy until March or April, 1919. These were only the most pressing needs, and an extended programme covering 221 engines to June, 1919, was put forward. A contemporary proposal to reserve the North British Railway capacity entirely for tanks was abandoned upon reference to the Army Council, who allocated priority in the following order: (1) mechanical transport spares; (2) railway material; (3) tanks.[1]

Foreign contracts during this period were few. Only one order for 40 engines was placed in America, and a few orders for spares for old contracts were also placed.[2] An order for 10 engines in Switzerland[3]

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[1] D.M.R.S. 434.
[2] R.M./Gen./113.
[3] This was negotiated at the end of 1917, but the necessary material came out of the 1918 allocation.

was also decided on in order to keep the Swiss capacity from being used by the Germans. One of the conditions of the contract was the provision of a certain amount of steel and ferro-manganese.[1] Delivery should have begun about February, 1918, but was postponed to the end of the year.

On the whole, however, British supply was sufficient to meet the needs of the Armies, and throughout 1918 due consideration was given to the importance of standardised manufacture.

III. The Supply of Ropeways.[2]

The production of the aerial ropeways projected late in 1917[3] involved special difficulties of its own, particularly in regard to the supply of wire rope in competition with the requirements of the Admiralty and the Air Service, and the provision of steel tubing for the "Hamilton" standards. Contracts for the various parts of the ropeways were placed with different firms for delivery to Purfleet, whence shipment of the entire units was made overseas. At the outset, deliveries were hampered by certain changes in design. Thus, a change in the pattern of the coupling rods for the Hamilton system led to some delay in supplying complete units. In the case of the Leeming ropeway, the limiting factor in supply was the power unit.

Trial units were tested in France during February 1918, but it was not until the following July that the first 20 miles of the two ropeways was complete. Considerable efforts were given to expediting supply, particularly the manufacture of backward items. By the beginning of October, 40 miles of the Leeming ropeway and 50 miles of the Hamilton system had been completed. The total requirement for 57[4] miles of the Leeming type was delivered by November, 1918, and 64 miles of Hamilton ropeway out of the 100 odd required had been completed by the same date.[5] The cost of the Leeming ropeway was about £1,500 per mile.[6]

IV. Increased Importance of Non-military Demands.

Throughout the war the needs of the home and colonial railways were necessarily placed somewhat below those of the military railways. The demands of war work for labour and material left little for domestic needs, and the consideration which was paid to non-military railways was itself due to their importance in the movement of troops and stores. This policy was summed up in a note of the Minister (Mr. Churchill) on the steel allocation for 1918 :–" Be careful not to

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[1] M.C. 221.
[2] R.M./Gen./53 ; W.22.
[3] *See* above, p. 3.
[4] *i.e.*, 50 miles originally required, together with 6 miles of spares and 1 mile for Salonika.
[5] (Printed) *Weekly Reports*, October, 1917–November, 1918, *passim*.
[6] M.E./L/194.

cut in upon munitions in the permanent peace-time interests of the railways, which are of importance only as they affect war-making capacity. It may be necessary to wear them out in winning the war. We must not aim at too high a standard at the expense of munitions."[1]

(a) HOME RAILWAYS.

It was not until the end of 1917 that the position of the home railways became serious. By that time, however, owing to very heavy traffic, withdrawals of rolling stock to France, and lack of replacements, they were in a very serious position. Renewal and maintenance programmes had been considerably reduced for three years. The mileage of lines re-laid in 1913, 1915, 1916, and 1917 respectively was 911, 695, 411, and 180. The Midland Railway had cut down the speed of its trains, and other railways expected to have to do so unless something drastic were done.

The railway companies normally required about 1,000 engines yearly, of which they made about 440 in their own shops. During 1914, 1915, and 1916 they bought only 734, their shops were occupied with munition work, and, in addition, during 1916 and 1917 they had sent nearly 600 out of the country. Further, 4,800 of their total stud of about 23,000 engines were awaiting repair, instead of the normal number, which was about 3,500, and many were running with a daily increasing risk of breakdown.[2] Finally, the repair of wagons by private companies had been much delayed by difficulties in obtaining labour and material. It had been found almost impossible to allow the home railways to obtain deliveries on their orders with contracting firms. For example, a single firm (Messrs. Beyer, Peacock) had orders on its books for both the London & North-Western and the Great Northern Railways which it was unable to complete owing to gun work. At the end of November, 1917, it was decided to take away these two orders, since the firm could not promise delivery within twelve months.[3]

It had also been excessively difficult to obtain materials, both plates and crank axles, the former owing to the overriding demands of the Admiralty and the latter to the pre-occupation of manufacturers with gun forgings. The Priority Department took up very strongly the supply of plates for engines, and as regards crank axles a certificate of high priority was given in order to obtain speedy delivery, as urgent work was held up by lack of these parts. The Railway Executive Committee had taken independent action for obtaining some relief by purchasing 18,000 tons of steel and some copper in America during the summer of 1917.

The requirements of the British railway companies for 1918 as finally put forward[4] were for 379 engines (in their own works), 836 boilers for repairs alone, 280 carriages to replace those sent abroad

[1] M.C. 256.
[2] These figures are those given by the Railway Executive Committee, 22.10.17 (M.C. 506).
[3] R.M./L/121 and M.C. 560; at the end of 1917 the first of these engines was promised for March and the last for the beginning of July. As a matter of fact, the first only was delivered at the end of October.
[4] At the meeting on 7.11.17 at the Board of Trade (M.C. 506).

for ambulance trains, and 12,740 wagons, or about 25 per cent. of their normal needs. They also needed 148,000 tons of rails and fastenings, and in addition 25,000 to 30,000 tons for points and crossings, all of which could be rolled at Crewe if hematite pig-iron were forthcoming. All the railway companies were so denuded of stocks of rails that very serious reductions in the speed over certain sections of the main line appeared inevitable.[1] The normal yearly requirement of rails was about 200,000 tons. Stocks of scrap had nearly all been disposed of. The total requirement in terms of steel was about 280,000 tons and 117,000 tons of iron. The chief items of the steel demand were 142,000 tons of rails, 11,700 tubes, and 34,800 plates, the most difficult item to supply. At the beginning of January, 1918, the Steel Department was arranging to meet these demands, but at the end of the month the Ministry had ruled that they must be reduced to allow material to be allocated for other purposes, particularly plates for building tanks and ships. By the beginning of February the programme had been reduced by 40,000 tons (including 500 tons of plates a month).[2] By the middle of the month, however, the allocation of steel to home railways was restricted to 50 per cent of the previous programme to meet the reduction of 100,000 tons which had been made in the Ministry's whole tonnage allocation. For the first five months of the year, however, it was proposed that the Railway Executive Committee should be allowed 20,000 tons a month, leaving 40,000 for the rest of the year, so that the latter amount might be increased if the position improved. It was suggested to the Committee (13 February, 1918) that the new stock-building programmes should be abandoned in order to economise in plates, but a certain allocation was promised if this proposal were not agreed to. The Committee protested in the most emphatic manner against the reduction. The material (66,000 tons) for repairs of engines, wagons, and carriages was absolutely essential; new boilers required 8,000 tons, and 32,000 tons were needed for new wagons, of which the need was pressing. There was left, therefore, only 9,000 tons for permanent way renewal and maintenance, and this inadequacy of supply would so much affect the efficiency of the railways that by the end of 1918, the Railway Executive Committee had no hesitation in saying, the railways would not be able to fulfil the requirements of the various Departments of State. To this the Ministry could only reiterate that the allocation could not possibly be increased. As events turned out, however, the home railways fared better than they had feared. For the first six months of the year they received 147,000 tons of steel, and were allowed 86,000 for the remainder of the year, roughly 230,000 tons in all.

The Railway Executive had throughout sent periodical statements of its programmes to the Railway Materials Department, and arranged

[1] M.C. 506.

[2] These are approximate figures only. The exact amount of the reduction was subject to frequent change with constantly shifting conditions of supply. The chief difficulty was experienced in regard to plates.

the supply of rails with the Steel Department. It was arranged for 1918 that the railway companies should part with 70 per cent. old rails for all new tonnage of rails allowed them.[1] The Steel Department was to let the Railway Executive Committee know the firms with whom orders should be placed, and the Committee was to place the contracts. The Chairman agreed as far as possible to place orders of not less than 500 tons of each section—this being the average output of a set of rolls.[2]

During the year 1918, owing to the exigencies of the iron ore trade, it was necessary to build nearly 4,400 hopper wagons for iron ore. A considerable number of wagons was hired from colliery companies for the ore trade, but this did not suffice to meet the situation, and the Department was forced to build, thus hampering to some extent supplies to France.

During 1918, considerable importance was laid upon the provision of railway materials in connection with a scheme which was set on foot by the Ministry of Shipping for diverting traffic from the east to west coast ports in case it became necessary to close the Channel to shipping.[3] The conveyance of the iron ore from the west coast to Middlesbrough could only be done by the northern route, *i.e.*, by a fleet of vessels sailing round the north of Scotland; but apart from this, the Ministry was concerned in the provision of additional railway material in case of a permanent diversion. There were two alternative schemes, the one temporary and the other permanent. The former entailed the provision of no additional railway material, being mainly dependent upon the organisation of large storage facilities. The "permanent" diversion for several months, however, entailed arrangements for transporting food across England from the western ports, Manchester, Liverpool, Cardiff, Avonmouth, and Birkenhead. The Railway Executive Committee stated that to build additional wagons in anticipation of the emergency was out of the question, and in any case existing goods services would have to be drastically cut down to clear the lines. The only provision needed, therefore, was that of additional unloading facilities at the ports. The total cost of the necessary sidings, shunting engines, and cranes was £210,000, and for this Treasury sanction was given on 9 May, 1918. The requirements consisted of 12 locomotives, three each for Liverpool and Cardiff, four for Manchester, and two for Bristol. As the Ministry of Shipping refused to take the engines unless an actual diversion of traffic took place, and as this emergency might never arise, it was decided not to order new engines, but to earmark engines already in use by certain firms, who agreed to release them at short notice in case of need. The total tonnage of the rails which would be needed was 2,200 tons. Some delay occurred before authorisation was finally received on 11 June, 1918, and subsequently in negotiations with the contractor and discussion as to the type of rail to be supplied. In September, in view of the urgent demands for rails at the front, it was suggested

[1] C.R.V./Gen./1564.
[2] *Ibid.*
[3] C.R.V./Gen./1611.

that the rails ordered under the diversion scheme should be used in France, but the greater part had by then already been laid in England. So far as the Ministry was concerned, therefore, the scheme resolved itself into the provision of 2,200 tons of rails for sidings at docks.

(b) Colonial and Foreign Railways.

Colonial locomotive orders had been under consideration early in 1916, when it was laid down that only engines of which 80 per cent. was already completed should be finished for colonial railways.[1] The War Office agreed that the requirements of British railways should take precedence of colonial requirements, but proposed that certain metre-gauge engines under construction for colonial railways should be completed in order that they might be taken over for military purposes if needed. The Ministry agreed to this in principle; but, at a later date, priority was refused for engines for West Africa even though more than 80 per cent. had been manufactured, owing to pressure of other work.

In September, 1916, certain demands, involving about 153 tons of steel, had also been put forward by the War Office for the Egyptian State Railways, as being of the utmost military importance.[2] Ultimately this work was given a first-class priority, and about a year later (November, 1917), 70 locomotives were ordered from the Baldwin Locomotive Company for the Egyptian Railways.

American railway shops were also utilised for the manufacture of 5,000 wagons for India (some of the parts for which had been ordered originally on Russian contracts) in view of the impossibility of meeting the demands in Great Britain,[3] and at the date of the Armistice negotiations were still proceeding for the manufacture of 60 to 100 locomotives for India by the Baldwin Locomotive Company. The South American railways, which had been in the habit of obtaining their stores in England, also decided on purchase in America, in 1918. They had originally formed a special Railway Stores Committee for the convenience of the Railways Priority Committee in order to deal with purchases in England.[4] As early as March, 1916, certain wagons ordered for South American railways had been commandeered for the French, and the possibility of obtaining second-hand metre-gauge rolling stock or engines from South America had also been considered.

The starving of the non-military railways had an additional advantage in that it necessitated the placing of fairly large orders as soon as conditions would permit, *i.e.*, when war contracts were being ended and orders were needed both to tide firms over from war to peace production and to absorb the enormous output of steel until industry was reorganised on a peace basis. Demands from the colonies and the South American railways were, therefore, eagerly awaited as soon as the Armistice had been signed, and the last stage of the Ministry activities was that of organising reconstruction orders.

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[1] C.R. 3145.
[2] D.M.R.S. 434 C.
[3] D.M.R.S. 332 A.
[4] D.D.G. (B) 138.

CHAPTER V.

THE CONTROL OF SECOND-HAND RAILWAY MATERIAL, 1916-1919.

I. Issue of a Control Order, December, 1916.

The activities of the Ministry were not confined solely to the supply of new railway material for use at the front, but were extended over a wider field by the assumption of control over dealings in second-hand materials. This was brought about by the issue of an Order[1] which was made by the Minister under the powers conferred on him by Defence of the Realm Regulation 30A, and prohibited all dealings in second-hand railway material without a permit. A wide interpretation was given to the Order in a court of law, when it was held to cover hire and purchase or any other form of agreement. A special branch of the Ministry was created to deal solely with the question of the necessary licences. Since the demand for these materials was so much greater than the supply, the control of dealings in second-hand stock was of exceptional importance.

This step was due to a rise in price and increased speculation in railway stores towards the end of 1916, when the general demand was rapidly increasing. The heavy demands from the front could only be met by a withdrawal of a number of wagons and locomotives from home circulation; munitions traffic was increasing, and French and other foreign buyers were competing in the market. Advantage was taken of this position by speculators and prices were being pushed up to limits which were considered unreasonable.[2] To counter this movement Sir Ernest Moir suggested in November, 1916, that control should be taken over all second-hand material, and on 29 December, 1916, the Order was published. This step, which was apparently taken without consultation with other Government Departments, was forced on the Ministry by its assumption of responsibility for supplying the needs of the armies in the field, and was intended chiefly to safeguard the interests of the State both in ensuring an adequate supply of goods wagons for munitions transport and for the front, and in securing cheaper purchase than existing speculations would have allowed. In fact, its scope was so extensive as to bring within the purview of the Ministry the whole of the trade in railway materials, whether for military or domestic purposes. It enabled the Department to mitigate the ill-effects of speculation in the hire and sale of wagons for the transport of necessities and was of particular utility in connection with the supply of wagons for coal.[3]

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[1] *See* Appendix II.
[2] M./Gen./53.
[3] R.M.L./Gen./42.

II. The Control Policy.[1]

The necessity for obtaining a licence for every transaction obliged every would-be seller or buyer to forward to the Department full particulars of the material in question, viz., its price, description, and destination, and as the granting of the permit lay entirely within the discretion of the Department there was scope for the application of a far-reaching policy.

(a) Priority for State Requirements.

Before any permit was granted the case was referred to any Government Department in need of the material concerned, and only when State requirements had been met was the transaction allowed. Although at first the Ministry provided only for its own requirements, in time the Admiralty and the Merchant Shipbuilding Department, the War Office, and the Office of Works communicated their needs for second-hand stock, especially engines and track, and were often put in touch with vendors. Much help was also given to the Board of Trade in 1918 in compiling a census of all railway wagons.

When the interests of the State had been satisfied, the system of permits was further used as a means of securing the diversion of material from less urgent to more urgent purposes, and also to prevent undue inflation of prices.

(b) Efforts to Eliminate the Middleman.

Experience of licensing soon showed that the excessive intervention of intermediaries between the first seller and the purchaser for use was one of the causes of the phenomenal rise in price of all kinds of railway material. In a somewhat notorious case the price of wagons bought by a gas company was increased by £27 owing to their having passed through the hands of two wagon dealers before reaching their ultimate user. "Sometimes three intermediaries figured in the transaction, and it was not uncommon for firms who had hitherto had no previous connection with the wagon trade to take a hand in this lucrative mode of business."[2] The efforts of the Department were directed increasingly towards altering this state of affairs. In November, 1917, it was suggested that a circular letter should be issued stating that the action of only one agent would be allowed between seller and ultimate buyer. Although this circular was never issued, the working of control was to this end, and wherever possible the action of the intervening agent was dispensed with entirely. It might at first sight be argued that this kind of action on the part of the Ministry, while technically within the power of the Order, was, in effect, beyond its purpose, and showed undue interference with private trading, which, however repugnant it might be in the opinion of the Ministry to sound organisation, was nevertheless legitimate. It must be realised, however, that quantities of railway material were always in demand for direct State purposes, and that any limiting of the action of agents could not be confined to

[1] Hist. Rec./H/1910/1.
[2] *Ibid.*

Government transactions alone. It was also considered within the Ministry that its action was of benefit to the industry of the country as a whole in putting some check on speculation in such a vital commodity as railway material.[1]

(c) THE LIMITATION OF RATES FOR THE PURCHASE AND HIRE OF WAGONS.

The system of permits was also used in practice to restrict prices for wagons, although no formal order fixing maximum prices was issued. During the year 1917 the Department was refusing permits when prices seemed exorbitant. In November, 1917, it was definitely proposed, when the restriction of the activities of middlemen was under consideration, that the Ministry should fix a maximum rate both for sale and hire of second-hand wagons. It was ruled in the Courts that the powers of the Ministry under the Order were of the widest and covered both these matters. The decision of the Court of Appeal (14–15 June, 1917) in the case, Anglo-Russian Merchant Traders, Ltd., v. John Batt and Company, London, Ltd., established that " the Regulation seems intended to control not only the price of this war material, but also the supply, which is limited; whereas the demand is practically unlimited." The fixing of the rates of sale was agreed in the Ministry but never publicly announced. At the beginning of December, 1917, sanction was given by the Secretary for limiting rates of sale, but it was thought that the power should be used with discretion. At a meeting of 27 February, 1918, Sir Ernest Moir suggested a scale of prices at double the pre-war rates. The old rate had been £70 for a new wagon and £10 for one 25 years old; the new rate was £140 for a new wagon, dropping by sliding scale to £40 for one 21 years old. The depreciation was steady. The Licences Department was to give sanction up to these limits and to issue permits only in accordance with this scale, while not informing the trade of the basis upon which it had been settled.[2]

The fixing of the rate at double pre-war prices was grounded upon the increased charges for repair and the enhanced value of the wagon in traffic owing to heavy home trade. The actual prices then being asked were £30 to £40 in excess of this scale. Apart from other considerations, as the Government was buying large numbers of wagons the resultant saving to the State would amount to no small sum.

The trade, however, was very critical of the Ministry's scale. Certain trade representatives, at a meeting on 3 October, 1918, put the starting point as high as £200, on the ground that the then replacement value was £200, arriving at that figure either by taking current cost of building a new wagon plus a reasonable profit, or by assuming a value of £160 to £170 after the war and adding compensation for loss of earning power at 12 per cent. per annum. On the other hand, Sir Ernest Moir maintained that there was no replacement value at the moment, that the scale did not apply to wagons built during the war, and that £140 would be a fair replacement value at the end of it, when building for

[1] M.C. 594.
[2] M.C. 389; M.C. 594.

private trade began again. It was also represented (by Sir John Mann) that the starting point of the scale had little value, as there was no free market in second-hand wagons, and that the Ministry had to consider the interests of both buyer and seller. The principles on which the Ministry and the trade took their stand were thus fundamentally opposed, the latter basing their price on the principle of replacement value at the time when prices were high on account of war conditions and actual replacement was impossible, and the former on that of probable post-war values when replacement would be really possible.[1]

The rate to be paid by the Government for second-hand wagons commandeered from colliery owners for the iron-ore trade was the subject of protracted negotiations between the Ministry and the Wagon Committee of the Mining Association of Great Britain. The wagons had been commandeered in April, 1917, and in September, 1918, the subject was still under discussion. The Ministry adhered to its scale (as above) while the Mining Association demanded £155 as the starting point of the scale, instead of £140. Sir Ernest Moir thought that this price was entirely fictitious, and that had there been a real market for wagons in April, 1917, it would not have reached this level.[2] Finally, to meet the owners, the Controller of Munitions Contracts agreed that, in addition to the Ministry price, interest at the rate of 5 per cent. per annum should be paid on the value of the wagons at the time of taking over. The wagons had by this time been commandeered for about 18 months. Various members of the Association refused these terms, and the matter was still under consideration in 1919.

The fixing of rates of hire was an even more difficult task owing to a considerable difference of opinion with the Railway Executive Committee as to what was a fair rate. Sir Ernest Moir and the Department were of opinion that the following prices were desirable: for a 10-ton wagon, 6*s*. a week; for a 12-ton wagon, 6*s*. 6*d*.; and for a 15-ton wagon, 7*s*. These rates were first suggested by the Licences Department in November, 1917, and were based on the necessity of imposing some check on soaring prices in view of the enhanced value given thereby to wagons which the Government might need to buy. The rise was out of all proportion to the general rise in prices, and it was thought to be due to the efforts of the wagon companies, who, anticipating that the Government would shortly commandeer all wagons, wished to enhance their value as much as possible, since their sale price would naturally rise with the increased hiring rate they could command. The proposed rates were based on the value of the wagon being twice its pre-war value, which necessitated an increased sinking fund charge on the weekly earnings of the wagon. Repair charges had also doubled. It was

[1] R.M.L./Gen./42.

[2] The effect of the war on the wagon industry is given in a letter to the Coal Controller from a contractor: "Owing to the war conditions and the stoppage of timber imports and high cost of steel and iron, also the action of the Government [in] taking practically all the output of wagon builders there are no new wagons being built for private traders." The fixing of replacement values, therefore, was not determined by actual market conditions. (R.M.L./Gen./42.)

considered, therefore, that a weekly charge of about 6s. would cover all the increased costs and leave the owner in relatively the same position as he was before the war, *i.e.*, give him a fair, but prevent an increasing, profit. The old rate had been 3s. 6d. for a 10-ton wagon, 2s. for depreciation, and 1s. 6d. for repairs.

The analogy of Blue Book rates for ships, and of the fixing of rents, was urged by Sir Ernest Moir in support of this attempt to fix rates of hire. By the middle of December, 1917, the principle had been agreed to in the Ministry and it was proposed to issue a Press notice stating that rates of hire would shortly be fixed. Before this was actually done the Admiralty, the War Office, the Coal Controller, and the Board of Trade were consulted. The latter was, however, negotiating through the Railway Executive Committee for the hire of 20,000 privately owned wagons at rates substantially higher than those suggested by the Ministry and desired the Ministry to suspend action until their bargain was concluded (9 January, 1918). Various meetings were subsequently held between the Board of Trade and the Ministry at which the latter set out the objections to the proposed rates, which were: 6s. 6d. for an 8-ton wagon; 7s. 3d. for a 10-ton wagon; 8s. 3d. for a 12-ton wagon.

The Railway Executive Committee based its rates on the earning value of the wagons and thought that they would be a good bargain if secured, while Sir E. Moir was of the opinion that "no case had been made out for profiteering in railway wagons," and stigmatised the demands as exorbitant. The alternative course of commandeering wagons was considered inadvisable in view of the difficulty of taking over repair contracts. On 20 March, 1918, the Ministry was notified that the Treasury had approved the Board of Trade rates, which indeed represented a substantial reduction on the prices then being asked in many quarters, viz., anything between 10s. and £1. The colliery companies were particularly hardly hit and the rate for iron-ore wagons had doubled since the outbreak of war, although their condition was said to be so bad that more than 40 per cent. were rarely in commission. Coal factors were also seriously affected, as, under the Prices of Coal Limitation Act, 1915, the price which the factor might charge to cover cost of conveying the coal to dealers was fixed, whereas the sum he might be asked for hire of wagons for this conveyance was unlimited. Hence many factors were losing heavily on the transport of their coal, and their total margin of profit was being encroached on. Lessees of wagons wrote to the Ministry asking to be protected from "what amounts to nothing else than blackmail in asking us to mortgage our future," for when hiring agreements ran out their renewal was being demanded at enormously increased rates for even so long as 5 or 7 years. The Department had, however, since December, 1917, been sanctioning agreements for short periods only.[1]

The Board of Trade being now out of the market the Ministry was free to go its way and was in doubt whether to adopt the higher or the lower rate. Departmental meetings were again held, and the Ministry tried to meet a deputation of the wagon owners, who repeatedly

[1] M.C. 389.

postponed their meeting. Finally it was agreed on 22 May that the Board of Trade rates should be adopted for the best wagons, but that lower prices might rule for inferior wagons, and on 27 June, 1918, a Press notice was issued fixing the rates of hire, about nine months after the suggestion was first made (1 November, 1917). At the same time that these rates were fixed it was announced that hiring agreements would be limited to six months after the war. From November, 1918, however, longer agreements were admitted provided that the rates were below the maximum and that both parties were agreed.[1] This modification was due to the representations of the trade, urging that congestion would ensue if all agreements lapsed at the same time, and did not constitute any attempt on the part of the Ministry to impose its rate after the war. The Ministry insisted on the insertion of the words " No terms of hiring which include an arrangement for the extension of the period of hire at the option of one of the parties only will be authorised " owing to the attempt of certain wagon lessors to make the extension contingent on their desire alone. The trade agreed without demur that extended agreements should only be allowed if the hiring rates were less than the Government maximum.

(*d*) Attempts to Control Wagon Repairs.

The repair problem had throughout been a difficult one, as it was not only partly responsible for the rise in wagon-hiring rates, but had also been alleged as a strong reason against the pooling of privately owned wagons, a scheme pressed by the Ministry at the beginning of 1918.[2] At the beginning of the year a combine of the chief wagon-owning companies was formed, under the title "Wagon Repairs Ltd.," to amalgamate their repairing activities. They issued, periodically, schedules of prices, each higher than the last.[3] In March, 1918, the Controller of Iron and Steel Production called the attention of the Railway Materials Department to the last schedule which had raised prices between 5 per cent. and 12 per cent., and stated that as things stood there was no chance of combating the rates. Consequently, it was decided that the Ministry should bring repairs, as well as manufacture, within its powers, under Regulation 2E of the Defence of the Realm Regulations, so as to enable a schedule of maximum prices to be issued. The assent of the Board of Trade was obtained in May and on 4 June, 1918, Regulation 2E was amended to run as follows :—

> " . . . the Ministry of Munitions may by order regulate, restrict, or prohibit the manufacture, use, purchase, sale, repair, delivery of any war material."

The real difficulty lay in fixing the schedule of prices to cover the complex operations involved, which numbered some 300. To obviate this trouble and the delay anticipated in overcoming it, it was suggested by the Licences Department that the Ministry, by its powers under

[1] M.C. 389.
[2] *See* below, p. 49.
[3] M.C. 612.

Regulation 8 of the Defence of the Realm Regulations, should take over and run all wagon-repairing depôts. The heavy traffic would, it was thought, necessitate fairly extensive repairs to both the Government and private wagons. It was not, however, considered that the time had yet arisen for so drastic a measure.[1]

The Explosives Supply Department, which had always made its own arrangements as to tank wagons, etc., did, however, set up two repair shops, one at Queen's Ferry, and the other at Gretna. At the former factory there was siding accommodation for 800 wagons, and with some addition to staff 150 wagons could have been dealt with weekly. The cost of the repairs was about 70 per cent. lower than the current trade prices.

(*e*) TRANSACTIONS IN LOCOMOTIVES AND SLEEPERS.

The action of the Ministry was not confined solely to wagons. There was considerable speculation both in locomotives and sleepers. Engines, for instance, might be bought as scrap for about £200, and with a few repairs done to them, resold for as much as £700 or £800. In one particular case, two engines were bought at 500 guineas each and offered to a railway company at double that price without any repairs whatever. Similar dealings in sleepers were also discovered and the price of roadway sleepers rose to as much as 15*s*. Finally the Ministry, in conjunction with the Railway Executive Committee and the Timber Controller, limited the price of sleepers as follows :—

Relayable Sleepers	7*s*. each.
Roadway Sleepers	4*s*. each.
Firewood Sleepers	30*s*. a ton (16 to 20 a ton).

(*f*) CONTROL OF DEALINGS IN RAILS.

Some confusion in regard to dealings in rails arose from the fact that, before the order subjecting transactions in second-hand railway materials was issued in December, 1916, the price of relayable rails, not being heavy steel melting scrap, of 50 lb. a yard and over had been fixed at £10 under the Steel Control Order of the previous November. As a general permit to deal in this class of material had thus been already issued by the Department of Iron and Steel Production there was abundant room for evasion of the subsequent order in regard to heavier rails. Light rails under 50 lb. a yard were meanwhile uncontrolled in price, and their market rate rose to even as much as £39. An amended control order was accordingly issued on 20 August, 1918, leaving the price of heavy rails untouched, but fixing the maximum price for rails between 33 lb. and 50 lb. at £12 a ton and of those under 30 lb. at £14. The order stated also that the general permit did not authorise any sale or purchase of any material coming within the Second-hand Railway Materials Order without a special permit granted under that Order.

[1] R.M.S. Gen./21 and 53.

III. The Scope of the Control.

(a) Special Relations with Wagon Finance Companies.

The administration of the Order of 29 December, 1916, by special licence rather than by general permit was modified toward the end of 1918 to suit the peculiar circumstances of the wagon finance companies. The value of the former method had been undoubted, for by this means the Department was able to investigate the past history of the material in question and bring to light several instances of profiteering. It was by this means, also, that it was made acquainted with the transactions in hiring which led to the Ministry's attempts to limit rates, and fix maximum prices of sale, while the knowledge obtained as to speculation in light steel rails was the cause of the application of maximum prices to steel rails under 50 lb. a yard in weight. The system of special licences also enabled the Department to see that regulations, once made, were not transgressed, and brought to light transactions which had been conducted illegally. In all these cases prosecutions were instituted and judgment was invariably given for the Crown.

The case of the wagon finance companies was, however, rather apart. The simple hire system presented no difficulties, but this was not the case with the hire-purchase system much in favour with wagon finance companies. Many transactions involved no more than the adjusting of financial relations, and there seemed no reason why a transaction between a finance company and a tenant having once come before the Ministry should be referred again owing to some modification in relationship, or some alteration in the terms.

The case for the finance companies was argued before the Ministry at a meeting on 2 September, 1918, and again in the following October, and was set out in a letter of 17 October, 1918, from Sir William Middlebrook to the Ministry. Having recited the position of the companies, the reduction in their business, and their recognition of the necessity for a check on profits he proposed :—

(1) that a general permit to continue the financing and refinancing of rolling stock should be given to the wagon finance companies, who should give in return an assurance to observe the Government maximum price in each transaction, and forward during the last week in every month a statement of all purely finance transactions entered into during the previous month ; and

(2) that in each transaction involving wagons acquired by the proposed tenant subsequently to the Order of 29 December, the permit number and date should be given.

To these proposals Sir Ernest Moir agreed, with the proviso that a special licence should still be required for the first transaction between the companies and any proposed tenant (*i.e.*, subsequent modifications would not need special permit). Later, on 3 December, 1918, the

companies replied, suggesting that in view of the Armistice, transactions mentioned in proposal (2) above should alone need a permit, *i.e.*, that new transactions when of a purely financial nature should be dealt with on the same lines as modifications of existing agreements. To this the Ministry assented.[1]

They also asked that the information given in application for permits should not be circulated to other Departments, but to this the Ministry could not agree, insisting on reserving to itself the right, if occasion arose and the interests of the State were to be served, to disclose this information.

(*b*) Centralised Control.

The effect of the Railway Materials Order would have been greatly weakened had the Ministry been referred to only in transactions concerning its particular firms. The Admiralty, however, agreed to refer to the Ministry all firms asking them for the issue of a permit so that there should be no evasion of the Control Order. This was done primarily to check contractors' material on Government work passing from firm to firm only to find its way ultimately to more Government work at a greatly increased price.[2]

The case of the railway companies was not so easily settled. The Railway Executive Committee had at first circularised all the controlled railways that they need not apply to the Ministry when disposing of any second-hand material; but the Committee was requested in March, 1917, to make it quite clear that the dealings of these companies came within the scope of the Order. Thereafter no question seems to have been raised on this matter, and in February, 1918, the Railway Executive Committee agreed that the railway companies should not even dispose of sleepers of any kind without reference to the Ministry.[3]

(*c*) Scheme for Pooling Privately-Owned Wagons.

The efforts of the Ministry did not end with the control of dealings in second-hand material, but were for some time directed toward furthering a scheme touching their use, *i.e.*, for the pooling of all privately-owned wagons.[4] In favour of the scheme it was alleged that it would result in economy both of engines and wagons—the former by diminishing shunting and the latter by ensuring that the wagons rarely or never travelled empty. The main difficulty concerned repairs. Sir E. Moir suggested, however, that the country should be divided into zones, each having a distinctive colour mark for its wagons, to which all its wagons should periodically return for overhaul, but never empty unless it could not be avoided. All wagons unfit for long travelling owing to defective grease boxes should be branded in some way. The wagons would be taken over at a hire rate. The

[1] R.M.L./Gen./42 and R.M./Gen./132.
[2] R.M.L./T./31.
[3] M.C. 259.
[4] M.C. 256.

differences in build of the majority of the wagons were thought to be small enough to be removed with little cost or labour.

The interest of the Ministry in such a scheme was very great owing to its having to provide steel for railway companies in 1918, and it was at a conference on this subject on 1 November, 1917, that the question was discussed with a view to reducing the wagon-building programme. At a conference held on 17 January, 1918, the obstacles to adopting the scheme were set out at length. The Railway Executive Committee, while entirely favourable in principle, regarded as insuperable such practical difficulties as lack of interchangeability in the wagons and difficulty of arranging for repairs.[1] They had contemplated a similar scheme in 1917, but had been convinced that the difficulties were insuperable. As regards the difficulty in regard to repairs, arrangements had been made by the owners for repair at the end of the journeys, but the railway companies could not possibly make such arrangements in the future. In fact, the common user of all railway-owned wagons alone had already in one instance brought about a grave position in regard to repairs, for the Great Western Railway had thereby been obliged to discontinue 55 express goods trains and to reduce the speed of the remainder from 60 to 40 miles an hour. Further, a large central organisation would be needed with a staff of expert manipulators such as the railway companies at the then stage of the war could not possibly supply.[2] It was considered that it would take five years for the scheme to get working and that the vested interests of the wagon finance companies would be too strong to allow of immediate action. These arguments carried the day and the proposal was dropped.

IV. Termination of the Control.

The Order of December, 1916, remained in force subject to the modifications made in regard to the wagon finance companies until February, 1919. On 7 February, an Order was issued suspending the control taken in 1916, except so far as it applied to the railway wagons of all types. Finally, on 14 March, 1919, the Order of 1916 was entirely suspended.

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[1] M.C. 256.
[2] R.M./Gen./36.

APPENDICES.

APPENDIX I.

(CHAPTER I, p. 4.)

Summary of Material supplied by the Railway Materials Department from May, 1916, to December, 1918.

STORE.	COUNTRY OF ORIGIN.			TOTAL.
	United Kingdom.	Canada.	U.S.A.	
Locomotives—				
4-ft. 8½-in. Gauge—				
New	289	40	485	814
Second-hand	700	—	—	700
60-cm. Gauge (New) ..	175	—	595	770
Metre Gauge (New)	50	—	—	50
Total	1,214	40	1,080	2,334
Tractors—				
4-ft. 8½-in. Gauge (New) ..	48	—	32	80
2-ft. 6-in. Gauge (New) ..	—	—	25	25
60-cm. Gauge (New) ..	1,037	—	—	1,037
Total	1,085	—	57	1,142
Wagons—				
4-ft. 8½-in. Gauge—				
New	28,097[1]	—	—	28,097[1]
Second-hand	27,500	—	—	27,500
60-cm. Gauge (New) ..	22,895	—	—	22,895
Metre Gauge (New)	1,000	—	—	1,000
Total	79,492	—	—	79,492
Track (in miles)—				
4-ft. 8½-in. Gauge—				
New	1,633	—	—	1,633
Second-hand	207	441	76	724
60-cm. Gauge (New)—				
20-lb.	3,383	—	—	3,383
9-lb.	918	—	—	918
Metre Gauge (New)	127	—	—	127
Total	6,268	441	76	6,785[2]

[1] 4,438 for the home ore trade.
[2] Exclusive of 553 miles from India.

APPENDIX II.

(CHAPTER V, p. 41.)

Order Controlling Dealings in Second-hand Railway Materials.

In pursuance of the powers conferred on him by Regulation 30A of the Defence of the Realm (Consolidation) Regulations, 1914, the Minister of Munitions HEREBY ORDERS that the War Material to which the Regulation applies shall include War Material of the following class and description, namely :—

Second-hand Railway Materials, including :—

Locomotives of all types.
Wagons of all types.
Rails of all sections and types.
Chairs.
Fish Plates.
Fastenings.
Signal Apparatus.
Sleepers, and the like.

NOTICE.

All applications for a permit in connection with the above Order should be addressed to the—

Deputy Director-General (Railway Materials Licences),
Ministry of Munitions,
Whitehall Place, S.W.

29 *December*, 1916.

VOLUME XII

THE SUPPLY OF MUNITIONS

PART VI

AGRICULTURAL MACHINERY

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PART VI.

AGRICULTURAL MACHINERY.

I. The Agricultural Machinery Department.

Towards the end of 1916, in consequence of the development of the submarine campaign the necessity for stimulating the output of home-grown food became apparent. At this time, nearly all the factories making agricultural machinery and implements were controlled by the Ministry of Munitions, and warlike stores were being produced to the virtual exclusion of normal output. A serious shortage of implements was thus threatened, and it was suggested that the Minister of Munitions, who also dealt with the supply of materials, labour and shipping space, should be made responsible for the supply of agricultural and dairy implements and machinery, although these did not come under the statutory definition of "munitions of war." On 24 November, 1916, the Cabinet decided in favour of the proposal.[1] The steps to be taken were then considered by the Advisory Committee of the Ministry of Munitions in consultation with the Food Controller and representatives of the Board of Agriculture and manufacturers; and on 2 January, 1917, Mr. Montagu appointed Mr. S. F. Edge to act as Director of the Agricultural Machinery Branch.[2]

The duties of the new organisation were clearly laid down at its inception. The Branch was not responsible for deciding the types and quantities of implements required, but for plácing contracts and so controlling manufacture as to secure an adequate output to meet the requirements formulated by the Food Production Department.[3] There was, moreover, no intention that the Branch should interfere with negotiations between farmers and manufacturers, and the requirements of users were to go direct to the makers through existing agents and merchants. Full returns, however, were to be obtained by the Ministry of Munitions, from all manufacturers, of stocks, orders in hand, and approximate time of completion, and of requirements for labour and materials. Future manufacture was to be regulated by a system of licences carrying the necessary priority.[4] The Agricultural Machinery Branch was also to have the power to change the allocation of orders, to arrange for extensions to works and to control imports. It was arranged that where firms were employed on munitions work, the possibility of enabling agricultural work to be put in hand immediately should be considered with the Area Organisation Department.[5] An Advisory

[1] A.C./15.
[2] *Ibid.*
[3] 94/M.T./248.
[4] See below, p. 3.
[5] A.C./15.

Committee was appointed with the Director as Chairman, consisting of six manufacturers,[1] representing different sections of the trade, one representative of the Food Production Department, and of each of the three Boards of Agriculture, and one representative of the Area Organisation, Labour Supply and Finance Departments of the Ministry of Munitions.[2] Representatives of importers, dealers and distributors were added at a later date. Close co-operation was maintained with the Agricultural Engineers' Association and the Implement Dealers' Association.

In May, 1917, the work of the Branch was considerably increased by the scheme for the manufacture, in this country, of motor tractors suitable for agricultural use on the lines of the Ford tractor. Mr. (later Sir Percival) Perry, a representative of Messrs. Henry Ford & Son, accepted the invitation of the Minister to assist the Branch in this matter. The Agricultural Machinery Branch was then reconstituted as the Agricultural Machinery Department, divided into a Permits and Materials Branch and a Manufacturing Branch, Mr. Edge being promoted to the rank of Controller.

In October, 1917, Mr. H. C. B. Underdown succeeded Mr. Edge as Controller, and the Department was re-organised into three sections dealing with Manufacture, Permits, Materials and Labour, and Imports and Exports. At the same time the Advisory Committee was converted into a Joint Advisory Committee serving both the Food Production Department, and the Agricultural Machinery Department.

In order efficiently to supervise production and render every assistance to firms in obtaining materials and labour, arrangements were made with the Department of Engineering under which inspecting engineers in each area were allocated to the Department. This system proved of the greatest possible value, as inspection carried out by a department of the Ministry specially equipped for the purpose, not only proved more effective, but was certainly more economical than the alternative system of the Department having its own inspectors.

In June, 1918, a Committee was set up by the War Cabinet Priority Committee to adjudicate between the competing claims of Government Departments for the products dealt with by the Agricultural Machinery Department.[3] This Committee held no meetings, as the competing claims were dealt with satisfactorily without reference to a higher authority. Its existence in the background, however, served a useful purpose and claims were dealt with which could not otherwise have been satisfactorily settled.

A chart showing the organisation of the Department in November, 1918, is given in Appendix VI.

[1] The six members appointed to represent the trade were:—Mr. Segar (Messrs. Richard Hornsby & Sons, Grantham); Mr. Bornemann (Messrs. Rushton, Proctor & Co., Lincoln); Mr. E. C. Ransome (Messrs. Ransome, Sims & Jefferies, Ipswich); Mr. J. Howard (Messrs. J. F. Howard Ltd., Bedford); Mr. R. H. Fowler (Messrs. John Fowler & Co., Ltd., Leeds); Mr. W. Harrison (Messrs. Harrison, McGregor & Co., Leigh, Lancs.).

[2] A.C./15.

[3] (Printed) Weekly Report No. 147, Section VIII. (22.6.18).

II. The Work of Supply.

(*a*) The Control of Manufacture.

The output of agricultural and dairy machinery and implements had suffered severely owing to the depletion of labour through enlistment and through transference to munition work, and to the manufacture of munitions by firms normally engaged on the production of agricultural machinery. Up to the end of 1916, the system in force with regard to the purchase of agricultural machinery and spare parts by the farmer, the blacksmith, and the dealer had been on the same lines as that adopted with regard to other industries controlled by the Ministry of Munitions—priority permits to purchase being required in every individual case. This was found to be impracticable in the case of agricultural machinery, owing to the importance of encouraging efficient distribution. The purchase of agricultural and dairy machinery and implements was, therefore, made free, and by an Order under the Defence of the Realm Act, dated 10 January, 1917, manufacture was prohibited without a Ministry of Munitions permit.[1] Permits were issued after scrutiny by the Agricultural Machinery Branch in consultation with the Board of Agriculture,[2] and P.5 priority classification was granted for all materials entered on the permit. Manufacturers were entitled to manufacture articles endorsed on the permit and to sell them direct or through an agent to anyone in the United Kingdom, but they were required to make monthly returns of output, and of the weights of materials used, records of which were kept.[3]

(*b*) Tractors and Ploughs.

In February, 1917, the Food Production Department of the Board of Agriculture was formed to organise a campaign to increase the acreage of arable land to the extent of three million acres. Farmers and landowners were urged to plough up their grassland; while, at the same time, the Food Production Department set up War Agricultural County Committees to facilitate the cultivation of land by the loan of government-owned tractors and machinery. The Food Production Department accordingly became extensive purchasers of agricultural machinery and implements, purchases being made on their behalf through the Agricultural Machinery Branch.

In view of the shortage of horses, the Government agricultural programme called for the immediate supply of very large numbers of tractors. Up to this date the manufacture of tractors in England had been on a very small scale. There were, therefore, two alternatives before the Government, namely, to import tractors from the U.S.A. or to manufacture on a large scale in this country. Shortage of shipping caused the second course to be most carefully

[1] Appendix I.

[2] For specimen permit, see Appendix II.

[3] For list of permits issued by the Department and the materials allocated under them, see Appendix III.

considered, and a meeting of manufacturers was called on 15 March to discuss the possibility of manufacturing tractors on a large scale. A deputation of agricultural machinery and motor manufacturers received on 14 April, advised that in view of the existing difficulties and the absolute necessity to provide tractors in the shortest possible time, it was essential that manufacture should be on the lines of a tried model. The "Fordson" tractor, manufactured by Messrs. Henry Ford & Son, of the U.S.A., was suggested in this connection, and, shortly after this, Mr. Henry Ford offered to present his tractor to the British Government as a model for manufacture, on the understanding that the tractors so manufactured should be purchased by the Government and not sold to private individuals. This offer was supplemented by a further offer to place all drawings, patterns, jigs, etc., and also the services of his works manager, chief draughtsmen and engineers, at the disposal of the British Government free of cost. The matter was further discussed, and on 20 April the Minister received a deputation consisting of the following gentlemen:—

Sir Herbert Austin (Messrs. The Austin Motor Co., Ltd.).
Mr. McCormack (Messrs. Wolseley Motors, Ltd.).
Mr. T. Hampson (Vulcan Motor Company).
Mr. I. L. James (Messrs. E. H. Dorman & Co., Ltd.).
Mr. T. Pullinger (Messrs. Arrol-Johnston, Ltd.).
Mr. Keene (Messrs. Austin Motor Co.), Secretary to the Committee.

As a result of these negotiations it was arranged that a trial of the "Fordson" tractor should take place under the auspices of the Royal Agricultural Society, at which members of this deputation should be present. The trial took place in due course, but owing to the shortness of notice the above-mentioned manufacturers were unable to be present. Two experts reported that the tractor passed the test with ease, and that a measured acre was ploughed in 1½ hours, paraffin consumption being 2⅛ gallons. On 1 May, on the representations of the above-mentioned manufacturers' representatives, it was arranged that an independent test by them of the "Fordson" tractor should take place in the presence of one of Messrs. Henry Ford & Son's engineers. The test was held on 3 May, 1917, by officials of the Ford Motor Co. under the observation of representatives of Messrs. Wolesley Motors Ltd., and the Austin Motor Company.[1] These firms subsequently submitted separate estimates of the cost of supplying these tractors, and a price was agreed with the Ministry of Munitions on the basis of these quotations.

The Manufacturers' Committee[2] advised, however, that the best way to secure the manufacture of tractors on a large scale was for the Ministry to undertake the assembly at a government factory of units to be manufactured at makers' own works. Mr. Ford's works manager and five experts reached this country in the middle of May, 1917, with full drawings and particulars, and invitations to supply estimates

[1] Hist. Rec./R/1950/7. [2] See above, p. 2.

were sent out to over 1,500 manufacturers. Tenders were received on 2 June. This plan had, however, to be abandoned almost immediately owing to the urgent demands for aero-engines and other munitions, which absorbed all engineering facilities available throughout the country. To meet this new situation, Mr. Henry Ford offered to supply the British Government with the whole of the parts for 6,000 M.O.M. tractors, these to be manufactured at Dearborn, in America, and to be shipped to this country for assembly in the Trafford Park factories, the price of such component parts not to exceed £150 per set. This offer was accepted in June, 1917.[1]

In May, 1917, arrangements were accordingly entered into, through the Ministry of Munitions Works Board and the Trafford Park Estates, Ltd., Manchester, for the erection of a factory and warehouse on land adjoining the works of the Ford Motor Co. (England), Ltd. The site was to be rented from the Trafford Park Estates at 6d. per yard per annum for the first three years and 1s. per yard per annum afterwards, and the factory to be put up by the Factory Construction Department of the Ministry of Munitions. As regards the lay-out and equipment of the buildings, the services of the Ford Motor Company, Ltd., were utilised. The factory was completed towards the end of the year, and ultimately cost approximately £90,000, the factory and equipment being the property of the Ministry of Munitions.

The assembly of the tractor parts, which began to arrive from America towards the end of 1917, was undertaken by the Ministry of Munitions on behalf of the Food Production Department of the Board of Agriculture. In October, 1917, Mr. Underdown decided that the work of assembly could only be efficiently carried out by appointing the Ford Motor Company (England), Ltd., contractors to the Ministry of Munitions for the work, not only as the quickest and most efficient way of getting it carried through, but also to avoid labour difficulties, which would have been insurmountable owing to the rates of pay in the adjoining factory of the Ford Motor Company being higher than the general district wages. A contract was accordingly entered into on 28 January, 1918,[2] and the government factory was handed over to the Ford Motor Company, who became responsible for assembling and storing, not only the 6,000 M.O.M. tractors manufactured at Dearborn, but also spare parts to the value of approximately £200,000, ordered under a separate contract,[3] and 3,750 Oliver ploughs ordered from Messrs. J. C. Mount & Co.[4] After many delays in shipment of parts from the States, owing to the general difficulties of the situation, 3,000 of the M.O.M. tractors were so assembled, the remaining 3,000 being delivered complete from the States in order to save time. After the contract had been completed the auditors of Messrs. Henry Ford & Son (Cork), Ltd., gave a certificate to the effect that the net cost price of the 6,000 tractors delivered to the British

[1] PM/MT/2900.
[2] PM/MT/5058.
[3] PM/MT/4116.
[4] PM/MT/3232.

Government was in excess of the sum of £140 per tractor which, with the low figure of £8 6s. per tractor for assembly cost, brought the total up to approximately £150, the price of the original contract.

In October, 1917, when Mr. Underdown succeeded Mr. Edge, steps were taken, in conjunction with the three Boards of Agriculture, and with the assistance of the trade, to form an estimate of the country's requirements in regard to agricultural and dairy machinery and implements. A detailed schedule was prepared, which became the basis for an intelligent policy whereby the shortage in supply of home manufactures could be overcome, and, at the same time, supplemented by Canadian and American importations, in such a way as to make the best possible use both of the manufacturing facilities in the United Kingdom and the very limited shipping space allotted to the Department for the purpose of importation.

The efforts of the Department to encourage the output of agricultural machinery at home were more and more seriously impeded by general difficulties due to the industrial war strain. While the shortage of shipping rendered the importation of the machinery and implements, required to make up the deficiency between the country's requirements and the manufactured output of the United Kingdom (normally amounting to only 70 per cent. of the country's requirements), extremely difficult of accomplishment.

(*c*) The Supply of Materials.

The principal materials employed in the manufacture of agricultural and dairy machinery and implements are cast iron, wrought iron, and malleable castings, mild steel, steel discard and tinned sheets and plates. Hard steel, brass, copper and zinc and spelter are also employed. The supply of these materials was already more or less bespoken for urgently required munitions and Admiralty work carrying the highest priority. Special difficulty arose in the case of malleable castings, and in order to meet it the Stampings and Castings Department of the Ministry agreed that the firm of Leys Malleable Castings Company, of Derby, one of the largest suppliers of castings to agricultural machinery manufacturers, should confine themselves for the period of five weeks to clearing up arrears of orders from such manufacturers. Special arrangements also had to be made with the Steel Production Department, with the Non-Ferrous Materials Department and the Timber Controller for ensuring the supply of the necessary materials. The increasing urgency of the position as regards shortage of materials rendered it obvious that a P.5 classification was not sufficiently high, and, accordingly, in January, 1918, the Department approached the Priority Department with a view to obtaining a higher priority, which request was sympathetically received and P.4 Class A. priority was recognised for all new manufactures. A little later, as the result of further urgent representations by the Department, P.1 priority was granted for the period of one month (February, 1918) as regards Government contracts for agricultural machinery and implements.

Tinned plate, terne plate, and black tinned sheets urgently required for milk churns, dairy utensils, sheep dip containers, etc., were in very short supply. Arrangements were made with the Priority Department and the Controller of Iron and Steel for the allotment of a definite quantity of these materials to this Department for allocation.

Coincident with the production of new machines and implements was the need for repairs to machinery and implements already in use. This meant that every blacksmith and implement repairer in the country had to be assisted to obtain the materials necessary for repair work. Arrangements were accordingly made, under which blacksmiths and repairers were enabled to obtain such materials for repairs up to the value of £5 without application being made. In addition to this, an arrangement was made with the Priority Department whereby all owners of steam ploughing sets, agricultural tractors, and similar machines were authorised to quote a P.4 priority to cover all repairs up to the value of £20 (excluding boiler plates, which were dealt with separately).

The shortage of wire for agricultural purposes was another of the many difficulties which had to be taken up by the Department. Owing to the large demands for barbed wire, for use by the army and for wire netting for the formation of tracks on the sand in Palestine and Mesopotamia, there was an extreme shortage of netting for agricultural purposes. As a result of strong representations by the Agricultural Machinery Department and the three Boards of Agriculture, a limited amount of wire netting was secured for agricultural purposes. Similar arrangements were made with regard to baling wire and fencing wire.

(*d*) Binder Twine.

One of the most difficult of the matters with which the Department was called upon to deal was the supply of binder twine, indispensable for harvesting purposes. At the request of the Board of Agriculture, the Department took in hand arrangements for the supply of a specified quantity of over 20,000 tons of twine, allowing for sinkings, and, after many meetings with the Hemp Controller, manufacturers of twine in this country and importers of twine manufactured abroad, agreements were eventually entered into for the manufacture in this country of 12,000 tons of binder twine, to be completed by 30 September, 1918, and for the importation of a further 6,200 tons by the same date. An agreement[1] was entered into with the various manufacturers and importers on 12 November, 1917, under which the twine was to be sold to farmers at £115 a ton, a price based on the then cost of raw material, plus the anticipated cost of manufacture, manufacturer's profit, and remuneration to dealers. The Ministry also agreed to take over, at a fixed price, any stocks unsold at the end of the contract year.

[1] PM/MT/3589.

While the twine was in course of manufacture, the serious shipping situation produced a shortage in the supplies of hemp and sisal and the Hemp Controller increased the price from £85 to £100 a ton.

The manufacturers also had to face increased wages to their workpeople imposed by the Ministry, as well as a rise generally in all their expenses, and they claimed that the selling price of the twine as originally fixed should be reconsidered, and that a fresh price should be substituted. The dealers also expressed themselves as dissatisfied with the remuneration allowed them on the original price, and pressed that it should be practically doubled. On the other hand, the Food Production Department pointed out that the price of £115 a ton fixed under the agreement was practically three times the pre-war cost of binder twine, and they were opposed to any alteration in the price. The difficulty with the dealers was overcome by increasing the selling price of the twine from a given date in respect of all unsold twine by £5 a ton to £120 a ton, and the manufacturers had to be content with an arrangement made after many conferences with the Hemp Controller to provide them with as much raw material as possible at the original price of £85 a ton.

In order to guard against any possible deficiency the Department called for a return of stocks of binder twine throughout the United Kingdom, and eventually arranged for the acquisition, on behalf of the Food Production Department of the Board of Agriculture, of certain large quantities in stock that were disclosed by this return. These stocks were purchased at favourable prices, but, even when added to the manufactured and imported twine, the total was not sufficient to remove the fear that the supply of twine would be inadequate. Further negotiations were therefore entered into with some of the manufacturers for the spinning of an additional quantity of twine, and moderate prices were arranged.

(*e*) Summary of Output.

In addition to the contract for the "Fordson" tractor, already referred to, and the American "Oliver" ploughs for use with the tractors,[1] which contract was finally completed towards the end of 1918, the following is a list of the principal orders executed on behalf of the Food Production Department of the Board of Agriculture :—

- 2,362 Titan tractors from International Harvester Company.
- 500 Caterpillar tractors, Messrs. Clayton & Shuttleworth.
- 400 Tractors, Saunderson Tractor Company, Ltd.
- 65 Sets steam ploughing tackle, Messrs. J. Fowler & Co., Ltd.
- 1,000 Disc harrows, Messrs. J. Wallace & Sons.
- 200 R.Y.L.T. ploughs, Ransome, Sims & Jefferies, Ltd.,

and from various contractors :—

- 1,000 Potato diggers.
- 500 Horse-drawn ploughs.

[1] See above, p. 5.

1,350 Cultivators.
1,680 Seed drills.
3,365 Rollers.
5,500 Harrows of ridged and jointed type.
546 Land presses.
5,000 Self-binders.
1,400 Disc harrows, tractor and horse-worked.
1,000 Horse-drawn farm tip-carts.
1,400 Horse-drawn flat top lorries.
1,750 Cultivators for tractors.
393 Threshing machines, 3 ft. 6 in. to 4 ft. 6 in.
6,000 Two-furrowed ploughs for "Ford" tractors of a special design.
3,750 Tons of binder twine.

Spare parts had to be provided for all these machines, and arrangements were made with the Pool Board (Petroleum Supplies) for a supply of paraffin and petrol for the tractors amounting to some 8,000,000 gallons.

Contracts were also executed for the War Office and the Home Office, and tractors were supplied to the Air Ministry, the Forage Committee, and the India Office for their own purposes.

The shortage of dairy apparatus was considered in conjunction with the Ministry of Food, and a Committee was set up, under Mr. Wilson-Harris as Chairman, composed of representatives of the three Boards of Agriculture and of the Agricultural Machinery Department, to ensure that there was a sufficient supply of apparatus to meet the requirements of dairy farmers. As a result of their activities, 80,000 10-gallon railway milk churns, 10,000 15 and 17-gallon milk churns, cheese vats, cheese moulds, curd mills, etc., were contracted for—drawings and specifications being largely prepared by Mr. Hiram, engineer to the Agricultural Organization Society, whose services were loaned to the above-mentioned Committee.

The total value of the contracts dealt with by the Department was approximately :—

During 1917	£3,200,000
During 1918	£1,500,000

(*f*) Labour Difficulties.

It has already been stated that the supply of labour for the manufacture of agricultural machinery was seriously affected by enlistment and by transfer to munitions work, and accordingly, early in 1917, it was agreed that this work should be considered as war work. This, however, did not take the matter far enough, as such work could not be regarded as munitions work in the fullest sense of the word, and to declare it "munitions work" would have necessitated the passing of an Act of Parliament. It was, therefore, necessary that steps should be taken to arrange for the protection from further enlistment of men engaged on the manufacture of

agricultural machinery. All manufacturers were asked to supply particulars in cases where their men were likely to be called up,[1] and their exemption was recommended to the Labour Department of the Ministry. In May, 1917, when the Schedule of Protected Occupations was instituted, arrangements were made for all manufacturing permit-holders to be entitled to protection.

Further arrangements were made with the Labour Departments of the Ministry and the War Office, under which applications for the release from the colours of men for the manufacture of agricultural machinery were dealt with in the same way as other applications supported by the Ministry of Munitions. But in the critical years of 1917 and 1918 release from the colours could only be granted in exceptional cases.

A bill enabling the Ministry of Munitions to declare the manufacture of agricultural machinery "munitions work" was brought before Parliament in May, 1917, but was not passed owing to the opposition of Labour to dilution on private work. Nevertheless, all the privileges which would have accrued from the passing of the bill were obtained through the efforts of the Department, with the one exception, that it was impossible to enforce dilution. As early in the war most of the men who had formerly been employed in the trade had either been enlisted or transferred to direct munitions work, the Department and the manufacturers had to contend all through with this disadvantage of shortage of labour which increased in proportion to the increasing demands on the man-power of the country. Efforts were continually made for the introduction of a special bill declaring agricultural machinery "munitions works," but without success owing to the opposition of labour to dilution.[2]

III. Control of Imports.

The control of imports of agricultural machinery was considered as soon as the Ministry of Munitions became responsible for the supply, and on 23 February, 1917, import without a licence was prohibited.[3] These licences were issued by the Department of Import Restrictions, but only after the application had been approved by the Agricultural Machinery Department. An Imports, Exports and Shipping Section was formed in March, 1917, to do this work, and, in order that importations should become effective, steps were taken through the Department of Munitions Overseas Transport to secure the requisite shipping space.

The American Exchange question became acute in the latter months of the year, and it was accordingly arranged with the Treasury and the American Branch of the Ministry that purchases in the United States should be carried out through the American Purchasing Commission, so as to avoid the remission of payments from this country

[1] Circular M.M. 81.
[2] L.R. 5997/37, L.R. 19046, M.C./2148.
[3] *London Gazette*, 1917, p. 1871.

to the U.S.A. Particulars were submitted to the Treasury of the expenditure to be made in this way and their sanction was obtained up to the sum of 1,500,000 dollars till 31 March, 1918. The position becoming more acute, the Department was then called upon to prepare a statement of the importation required by it from America. This statement[1] was submitted to the American Board, which had been set up under the Chairmanship of Mr. Austen Chamberlain to authorise the placing of orders for munitions in the U.S.A. The statement submitted and approved was based on the estimate previously referred to of the country's requirements and represented the importations necessary to fulfil these requirements after allowing for home manufacture.[2]

As a result of the decision of the U.S.A. to enter the war, the American Government imposed regulations in regard to the manufacture and export of goods from the U.S.A. and insisted upon all orders placed with American manufacturers being placed directly by the British Government as being vitally necessary for the conduct of the war. A great deal of time and labour was involved in communicating through the American Branch of the Ministry with the Treasury and the British Purchasing Commission in New York on the one hand, and the Contracts Department of the Ministry on the other, with a view to setting up a procedure which should involve the importer in as little inconvenience and expense as possible, and at the same time obviate delay in the completion and forwarding of goods. Eventually importers were advised that all future orders for goods from America must be placed through the medium of the Agricultural Machinery Department, the Government in effect acting as purchasers of the goods, and reselling them to the importer upon arrival in this country. The Department was from the first opposed to this arrangement on the ground that it would not only involve the Government in expenses and risks which were unnecessary, besides increasing the cost of the article eventually to the user, but, what was of more serious import, would cause delay in the placing of the orders, and in the shipment of the goods and their arrival on this side.

Under this procedure some sixty orders were placed by the Government with the American suppliers at the request of importers, but the result was very unsatisfactory. Much delay took place before the orders were placed by the British Purchasing Commission in U.S.A. for reasons that have been explained, and the majority of the goods ordered arrived in this country too late for the work for which they had been ordered. It must be understood that agricultural work is entirely seasonal, and the various goods must be here by stated months of the year; otherwise they lie in stock until the corresponding season arrives in the following year. It is a serious hardship to the importer since it locks up his capital and occupies much needed store-room for many months. In this instance it proved still more serious, because, owing to the delays above referred to the country was short of agricultural implements when they were required, and shipping space

[1] A.B./Reqn. 10/11. [2] See above, p. 6.

was taken up by the transit of these goods that should have been occupied by other goods necessary to the season. As a result, urgent representations were made by the Department through the American Branch to the British Purchasing Commission, to induce the American Government to withdraw this procedure, and to substitute in its place the issue by this Department of permit numbers to importers, allowing the latter on obtaining the consent of this Department, to negotiate with manufacturers in U.S.A. for the supply of their requirements. After much effort this was, with great reluctance, conceded by the American authorities, and in practice the system of the Agricultural Machinery Department permit numbers proved satisfactory, and provided an adequate importation of agricultural machinery and implements to meet the needs of the United Kingdom.

By the middle of 1917, the enormous rise in shipping freights threatened to curtail the importation of urgently required machinery and to cause the cost to farmers to be prohibitive. Consultations therefore took place with the Food Production Department, as a result of which the Shipping Controller was approached, and, with the assent of the Treasury, the government rate of freight was granted in respect of all importations of agricultural machinery and implements from the U.S.A. and Canada to this country on condition that the prices of such importations were controlled by this Department.

Importers and dealers were then consulted, and, in October, 1917, it was decided to fix the controlled price at the actual cost to the importer at his principal place of business (including cost of erection), plus 25 per cent. on such cost. The conditions under which import licences were to be issued were discussed with the Board of Trade and a form was agreed upon.[1] Following on representations made in September, 1918, by importers as to the insufficiency of the margin of profit allowed upon the cost price of the goods, meetings were held with importers and dealers, and the books of some of the chief firms were inspected with a view to ascertaining whether an increase in the percentage profit allowed could be justified. As a result, importers were notified in November, 1918, that, in addition to 12½ per cent. for on-cost not previously allowed, the rate of profit that they would be allowed to add to their cost here would be 25 per cent. in respect of goods sold to the user at a price not exceeding £40, and 17½ per cent. upon articles sold to the user at a price exceeding £40. At the same time it was agreed to make a stated allowance for erection charges, and also for carriage of goods to the user, it being demonstrated to the satisfaction of the Department, that it was the general custom of the trade to deliver goods free. While these concessions did not altogether satisfy the demands of importers, it was not seriously contended that they did not give a fair profit to the importer, and a reasonable remuneration to the dealer.

The control of the price of imported goods, involving an infinite variety of practically every class of agricultural machine and implement, threw an enormous amount of work upon this Department in connection

[1] M.C./10.

with the checking of the price of the article, shipping and transit charges, the erecting expenses, etc., before arriving at the controlled price at which the article must eventually be sold to the user in this country. There was also a very considerable amount of enquiry work in regard to the shipment of goods, the ascertainment of their whereabouts from time to time, and their release on arrival in this country, as well as obtaining from importers a certificate entitling them to the Government rate of freight where, in the absence of other instructions, the shipping companies had imposed the full rate.

The necessity for restricting importation to the lowest possible figure was rendered all the more important owing to the further increasing shortage of shipping. In June, 1918, it became necessary to stop the open importation of tractors, and only to recommend the issue of licences for such as had been definitely purchased by farmers. This gave rise to many complaints, but the shipping situation made it impossible to withdraw the regulation, and, as matters eventuated, there was never any real shortage of these machines. A rationing scheme was also prepared for goods to be imported during the year 1 July, 1918, to 30 June, 1919, under which each registered importer was notified that he would be permitted to import a specified number of the various machines and implements in proportion to his imports for the previous year. This programme, which entailed much labour, was in due course submitted to the Treasury, and sanction was obtained for the placing of orders in U.S.A. for the goods specified therein, totalling altogether 10,215,500 dollars. It may be interesting to record that the actual cost of the goods ordered under the rationing scheme was 9,190,067 dollars 84 cents, which was slightly under the figure submitted by the Department to the Treasury. The following were the actual figures of goods ordered from America and Canada under the scheme :—

Binders	$1,417,850·00
Binder forecarriages	5,135·72
Drills	446,542·60
Reapers	67,905·89
Reaper attachments	39,737·50
Hay tedders	37,134·65
Engines	659,045·10
Spare parts	1,065,433·15
Silo fillers	4,434·11
Mowers	286,031·43
Cultivators	28,178·50
Harrows	579,691·79
Ploughs	539,426·43
Plough bottoms and parts	433,837·42
Tractors	3,328,606·25
Miscellaneous	249,814·80
Tractor hitches	1,262·50
Total	$9,190,067·84

In the spring of 1918 heavy snowfalls and the general dislocation of traffic upon the American and Canadian railways still further increased the difficulties. The delays involved in the forwarding of goods, which were, of course, unavoidable, called for practically daily cable communication between the Department and the Government shipping agents in New York and in Canada. In spite of difficulties that must have been tremendous, a very large proportion of the agricultural goods that were so badly needed in this country were put on board at American and Canadian ports and arrived in this country in time to permit of the Government's land cultivation scheme being carried out almost in its entirety. It may be added in connection with the shipping question that the Imports and Exports Section was required each month to make a forecast of its requirements of space both from America and Canada, and to appear before the Shipping Committee of the Ministry in support thereof. On no occasion was a demand made upon that Committee refused, due in part, no doubt, to the fact that the Cabinet decided that agricultural machinery and implements must rank immediately after foodstuffs in the shipping programme.

The pressing needs of the war, both as regards material and labour, greatly encroached upon the works of manufacturers of agricultural machinery and implements, with the result that the anticipated output was seldom reached, and this in turn necessitated arrangements being made by this Department for the importation of further goods. Action so taken was mainly upon the urgent representations of the Board of Agriculture.

A very large number of small agricultural tools and handles, therefore, were required to be imported from U.S.A., but they were not regarded as coming within the province of the Agricultural Machinery Department, being dealt with by the Department of Import Restrictions at the Board of Trade. Eventually, the Board of Trade declined to issue the necessary import licences for such goods except upon the recommendation of the Imports and Exports Section of this Department, and a considerable amount of work was necessitated in ascertaining from various sources what the position was in regard to these tools, and, in particular, what supplies of handles were available in this country.

IV. Control of Exports.

The shortage of agricultural machinery and materials led to the control of exports at an early date. On 12 December, 1916, the export of agricultural machinery to all places other than British Possessions and Protectorates was prohibited without a licence,[1] and on 10 May, 1917, it became necessary to extend this restriction to all destinations.[2] As in the case of imports, applications for licence to export were examined by the Agricultural Machinery Department before being

[1] *London Gazette*, 1916, p. 12121.

[2] *London Gazette*, 1917, p. 4489.

dealt with by the War Trade or Priority Departments. From March to December, 1917, inclusive, some 10,500 applications of this nature were dealt with, but during this period the work was not so intricate as it afterwards became for reasons which will appear.

During 1918, some 5,500 export applications were dealt with, and the bulk of these were referred back for reconsideration. It can be readily understood that manufacturers were desirous of maintaining, so far as possible, their export trade, and, in consequence, a large number of applications were daily submitted by manufacturers to the Priority Department for material with which to manufacture both complete articles and spare parts for export. Each of these applications was submitted to this section for advice, and had to be carefully considered upon its merits, the first regard of the Department being to see that the manufacture of goods for export would not materially affect the output of the manufacturers of goods required for the United Kingdom. It was found, in consequence, to be impossible to recommend to the Priority Department the granting of a permit for the issue of material in a large number of instances, but special consideration was shown throughout the whole period to the requirements of the Colonies and to those countries that were producing food and other commodities that eventually found their way here. The Edge Tool Manufacturers, for example, supplied large quantities of tools to the Colonies and to allied and neutral countries. They were specially equipped for this class of work, and maintained that they could not continue manufacture if their export trade were cut off. Their case was carefully considered, and in June, 1917, it was decided to grant them permits to manufacture for export.[1] In order to arrive at a decision, it was necessary for the section to communicate with a large number of other Government Departments, notably the Sugar Commission, the Hemp Controller, and the Food Controller. On the few occasions when the decisions given by the section in regard to applications for export were questioned by the Foreign Office, by the Colonial Office, or by the High Commissioners for the Colonies, it was demonstrated that such decisions had been based upon sound grounds, and they were generally accepted as conclusive.

V. Control of Prices.

(*a*) Sale Order of June, 1918.

In April, 1918, it was decided to institute price control of home manufactured agricultural and dairy machinery and implements and a Price Control Section was set up under Mr. J. J. Ure, a chartered accountant, after consultation with the Board of Agriculture and the Scottish and Irish Offices. Up to that date, the Department had no evidence of any general profiteering on the part of manufacturers or their agents. In view, however, not only of the continued shortage of supplies (brought about partly by increased requirements and partly by the reduction of output consequent on shortage of labour

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[1] (Printed) Weekly Report, XXIII. 95, Section IV. (9/6/17).

and material) but also of the large increases which had taken place in costs of production, it was imperative that prices charged to farmers should be subject to control. The fact that since January, 1918, prices of imported machinery and implements had been controlled through the licences issued to importers by the Board of Trade, constituted a further argument in favour of controlling prices of home-manufactured agricultural machinery and implements. Control of imported prices had been imposed to counterbalance the preferential treatment received by importers as to Government shipping space and freight rates, and restriction of home manufacturers' prices was a natural corollary to the restriction of imported prices.[1]

After preliminary discussions of great value with the Machine Tool Department of the Ministry, which had been controlling prices of machine tools for a considerable period, the first and most desirable, but by no means easy step, was to obtain the goodwill and co-operation of the principal manufacturers and dealers. Meetings of the Advisory Committee, and of representative implement dealers, were accordingly held early in May, 1918, and at these meetings the necessity for the policy of controlling prices was explained and approved, and the general principles of the scheme agreed to. A Price Control Committee was appointed, consisting of representatives of both sections of the trade, for the purpose of advising and assisting the Department. Later, small consultative Sub-Committees for each branch of manufacture were formed.

The form and method of control to be adopted called for very careful consideration in view of the great variety of machines, implements, etc., manufactured under permit of this Department. It was finally decided to effect control in the following manner :—

(1) By embodying in all manufacturing permits a condition that prices to agents or users must not, without the sanction of the Department, exceed those ruling in each manufacturer's business on 1 April, 1918. Such prices were, in addition, subject to reduction or modification as the Department might direct.

(2) By limiting, by means of a new Sale Order, the amount of commission an agent or dealer was entitled to add to the net prices charged to him by manufacturers.

It will be observed that under (1) the Department reserved the right to question any existing prices which were considered unreasonable.

As already stated, the general principles of this scheme were submitted and approved by representatives of the trade at the meetings held in May, 1918, while the actual terms of the new regulations and new Sale Order were fully considered and approved by the Price Control Committee.

Under the Sale Order,[2] which was published on 21 June, 1918, the maximum profit allowed to agents and dealers was 17½ per cent.

[1] See above, p. 12. [2] Appendix IV.

on articles costing £40 and upwards, and 25 per cent. on articles costing under £40; such percentages corresponding to discounts of approximately 15 per cent. and 20 per cent. respectively off the maximum list prices chargeable. These percentages were decided upon after taking into consideration the custom of the trade and the expenses of distribution and allowed for a reasonable net profit to agents and dealers. The considerations leading to this adoption were as follows :—

(1) In the Agricultural Machinery Trade it is a recognised custom to allow the farmer or user a discount of 5 per cent. for cash, which has to come out of the agent's commission. This discount being calculated on list prices reduces the agent's commission to $11\frac{5}{8}$ per cent. on implements over £40 and $18\frac{3}{4}$ per cent. on implements under £40.

(2) The percentages were, generally speaking, lower than those ruling in the trade before the war. It would have been suicidal to have attempted to reduce the percentages still further and so risk the interruption of the distribution of absolutely vital machinery and implements. Few trades depend more on the middleman as regards distribution.

(3) The Department had to guard the interests of the private user, which interests were immeasurably larger than those connected with Government contracts handled by the Department. In other words, it had to do everything to see that the farmer's requirements were fulfilled quite apart from Government contracts.

(4) The agricultural machinery agent has to give "service" as regards the machinery and implements which he distributes after they have passed into use, and this "service" is not, except in exceptional cases, paid for.

(5) Agents, owing to the trade being seasonal, have to carry a considerable quantity of stock, and the financing of the stock comes out of the agent's commission.

(*b*) Investigation of Prices Ruling on 1 April, 1918.

Immediately on price control coming into force, the first matter taken in hand by the Department was a general investigation as to the justification for the prices ruling at 1 April, 1918.

In May, 1918, a questionnaire had been issued to each manufacturing permit holder, requesting the return of net prices charged to agents for agricultural and dairy machines and implements ruling in their respective businesses on 1 January, 1914, 1 January, 1916, and 1 April, 1918. There were then approximately 1,200 permit holders, but only about 50 per cent. of the questionnaires were returned completed. This is accounted for by the fact that the great bulk of the manufacturing trade is in the hands of about 100 large firms, the majority of whom are members of the Agricultural

Engineers' Association, the remainder of the permit-holders being small blacksmiths and manufacturing ironmongers who only manufacture in very small quantities for local customers and who have no fixed schedule of prices.

All prices given on the questionnaires returned were examined for the purpose of ascertaining the percentage increase which had taken place at 1 April, 1918, since 1 January, 1914. The Department agreed as a general principle not to question prices ruling at 1 January, 1914, as it was satisfied that such prices were reasonable and included no undue profit. As a matter of fact prices at that date were being very considerably cut in order to meet keen competition, especially from America, and examination of manufacturers' costs has since proved that, in many cases, machines and implements were being sold at a loss before the war. It was, therefore, decided that 1 January, 1914 prices should form the real basis of control, and all existing prices be considered in the light of increased cost of production since that date.

It was obviously impossible for many reasons to go fully into the manufacturing costs of each manufacturer, and it was, therefore, decided only to call for particulars of the costs of the principal firms. These particulars would then serve as a guide in arriving at justifiable percentages of increase applicable to the prices of each class of implement since 1 January, 1914, having regard to the increase in cost of production. The existing prices of all other manufacturers could then be tested as to their reasonableness or otherwise by the application of such percentages to the pre-war prices.

In order to avoid detailed examination of the principal manufacturers' books, it was decided, on the suggestion of the Price Control Committee, to issue forms which could be completed by each principal manufacturer, giving particulars as to prices and costs of representative types of implements. On the original draft of this form being submitted to the Committee, objection was taken to particulars being asked for which would disclose the net profit made by manufacturers on each class of implement; the reason given being that these forms might have to come before members of the Committee who were also manufacturers of similar implements. This objection was so unanimously held by the Committee that the Department considered it advisable not to call for such particulars in the first instance, but to reserve the right to do so if and when necessary. It was finally agreed, therefore, to restrict the particulars asked for to selling prices, cost of material, cost of wages, as at 1 January, 1914, 1 April, 1918, and the date at which the form was completed, the particulars at the last date being required in support of any application to advance prices over those of 1 April, 1918.

Approximately, 400 forms were issued in the first instance to about 70 of the large manufacturers, and over 200 were completed and returned. The examination of these had to be on fairly broad lines owing to the absence of particulars as to overhead charges and

profit, but, generally speaking, it was found that increases in prices only allowed for a moderate increase in respect of charges and profit, and were considerably below the rate of advance in material and labour.

(c) INCREASE IN PRICES.

By the time these forms had been returned (October, 1918), applications for further advances in prices had been received, owing to the fact that prices ruling on 1 April, 1918, were no longer remunerative by reason of advances in costs. It was accordingly decided that the percentages of advance to be considered reasonable since 1 January, 1914, should be arrived at on the basis of increased costs down to October, 1918, instead of April, 1918. By far the greater part of the Agricultural Implement Trade is seasonal, and in many cases prices which were ruling on 1 April, 1918, had been actually fixed and been in existence since October or November, 1917. Consequently, such prices did not make allowance foı increases in cost of manufacture which had occurred during the previous twelve months.

The Sub-Committees appointed by the Price Control Committee to deal with the prices of each class of implement rendered very valuable assistance to the Department in arriving at the percentage advance in respect of each class. Although the members of these Sub-Committees were personally interested in the maximum prices arrived at, it is satisfactory to state that they all endeavoured to uphold the principles of price control by advising the Department to the best of their knowledge and ability, and as far as possible without prejudice.

A maximum percentage of increase was arrived at by the Department in respect of each class of implement.[1] It will be observed that in practically every case the maximum is in excess of the average percentage ultimately granted to manufacturers who claimed advances over the prices ruling on 1 April, 1918. Cases where the reverse is shown are accounted for by exceptional circumstances as regards particular manufacturers' prices at 1 April, 1918, which justified an advance greater than the maximum decided upon. In arriving at these maximum percentages certain important factors had to be taken into consideration. It was of vital importance to encourage the production of agricultural machinery by sanctioning such prices as would allow of a reasonable profit being made by manufacturers. If the Department had attempted in any way to force manufacturers to accept a fixed low rate of profit on their turnover, output would have been materially reduced, as practically all of the principal manufacturers were largely engaged in the manufacture of munitions and not wholly dependent on their agricultural machinery trade. Another point already referred to was that owing to very keen competition in 1914, the prices of many implements at that time allowed of little or no profit to the manufacturer. On satisfactory evidence being produced in each

[1] See Appendix V.

case an advance in price was allowed sufficient, not only to cover the actual increase in cost of production, but also to give the manufacturer a reasonable rate of profit.

The prices on 1 April, 1918, of all other manufacturers, who had not been asked to complete any forms, were examined in the light of the maximum percentages, and it was found that, except in very few cases, prices of October, 1918, were reasonable.

The total number of firms who applied during the period of control for permission to advance their prices was 164. Of these 20 failed to supply the Department with the necessary information as to their manufacturing costs, and consequently no advance was sanctioned in their cases. At first sight, this number of applications appears small in comparison with the total number holding permits to manufacture, but a great number of these permit-holders were in a very small way of business, and probably had either manufactured and sold the articles authorised by their permits prior to price control coming into force or were unable to manufacture through difficulty in getting material and labour. At the same time the total number of forms which had to be examined was just over 400, each one representing a different type of implement, and really constituting a separate application. In the case of 51 per cent. of these, the advances asked for were granted in full, 34 per cent. were granted a reduced advance, and 15 per cent. were refused any advance on the prices ruling on 1 April, 1918. The second and third columns of the attached table[1] give the average advances sanctioned as regards list and net prices ruling on 1 January, 1914. It will be observed that, in all cases, the advance in list prices is considerably below that in the case of net prices. The explanation of this is that the discounts allowed to agents by the Sale Order were on the average lower than those ruling in the trade in 1914. In other words, part of the increased cost of manufacture was being met out of the agents' commission. In several cases the particulars returned by manufacturers were unsatisfactory, and fuller information as to costs was called for, certified balance-sheets having, in some cases, to be produced before the Department's decision was given.

(*d*) Inspection of Prices Charged.

Owing to extreme difficulty in obtaining a qualified inspector, it was not until towards the end of the period of control that any systematic inspection could be carried out with the object of satisfying the Department that the price regulations were generally being adhered to. Several cases were investigated where the Department had reason to believe that the regulations were being broken, and in a few instances firms were made to refund to their customers all sums charged in excess of prices authorised. Mr. Collin Bishop, who was ultimately appointed to the Department, examined, prior to the suspension of control, the books of 45 agents in various parts

[1] See Appendix V.

of the country. So far as this examination went, he found no cases of systematic evasion by agents of the Sale Order, and although there were several instances where farmers had been charged more than the maximum prices, the amounts in question were, generally speaking, comparatively small, and had been charged in ignorance or under misunderstanding of the Order. Such overcharges were refunded by order of the Department.

(*e*) Sale Permits for Retail Traders.

Reference should be made to the issue of sale permits which were necessary (under Clause 1 of the Order) where implements had not been purchased by agents direct from the actual manufacturers. Two forms of permit were adopted—one, a Special Sale Permit, applicable only to a specified article; the other, a General Sale Permit, applicable in cases where an agent obtained considerable supplies from time to time from another agent or wholesale dealer. These permits were necessary in order that the sub-agent might be advised of the maximum sale price. As regards the Special Permits, the maximum price of the implement was ascertained and inserted on the permit. In the case of General Permits, these had to be applied for on behalf of the sub-agent by the wholesale dealers, and on the application form the latter had to give an undertaking to inform the sub-agent of the maximum prices at which implements supplied could be sold.

Considering the large number of agents in Great Britain, the total number of permits issued was comparatively small, due no doubt to agents purchasing direct from the manufacturers. In Ireland, however, a very large number of General Permits had to be issued, as nearly all agents there obtain their supplies through importers. The issue of these permits was undertaken by the Institute of Agriculture and Technical Instruction in Dublin.

(*f*) Summary.

There is no doubt that the Government control of prices of agricultural and dairy machines and implements was fully justified by results. The almost entire absence of complaints received by the Department from agricultural committees or farmers supports the view that the maximum prices as fixed were not considered unreasonable, having regard to the abnormal conditions ruling in the trade There is no doubt that much of the success of price control was due to the loyal co-operation of the principal manufacturers and dealers, but at the same time the necessity of supplying the department with particulars of manufacturing costs in support of any application for an advance in price had a restraining influence on manufacturers in formulating their claims, as any claims which did not appear justified would lay the applicants open to suspicion, and thereby defeat the object of the application.

VI. Conclusion of the Department's Work.

The signing of the Armistice in November, 1918, did not immediately affect the work of the Agricultural Machinery Department in the same way as other departments of the Ministry, and it was felt desirable that for some time, at any rate, control should continue. This policy was pursued.

In January, 1919, Mr. Underdown submitted suggestions to the Minister for the lifting and suspension of control by the Department of manufacture, imports, and prices, in return for an undertaking by the manufacturers that they would safeguard home requirements before dealing with export demands. This suggestion was laid before the three Boards of Agriculture and the Board of Trade, and approved. A meeting was convened on 5 February by the Agricultural Machinery Department in conjunction with the Food Production Department, at which members of the Advisory Committee and a representative of the Agricultural Engineers' Association and the Implement Dealers' Association were present. At this meeting the undertaking referred to was given, and the following Order was accordingly published in the Press on 14 February, 1919:—

> "In reference to the following orders made by the Minister of Munitions, namely:—
>
> The Agricultural Machines, Implements and Vehicles (Manufacture) Order, 1917, dated 10 January, 1917.
>
> The Agricultural and Dairy Machines, Implements and Vehicles (Sale) Order, 1918, dated 21 June, 1918.
>
> The Minister of Munitions hereby orders as follows:—
>
> (1) The operation of the said Orders is hereby suspended on and after 14 February, 1919, until further notice.
>
> (2) Such suspension shall not affect the previous operation of the said Orders or either of them or the validity of any action taken thereunder, or the liability to any penalty or punishment in respect of any contravention or failure to comply with the said Orders prior to such suspension or any proceeding or remedy in respect of such penalty or punishment.
>
> (3) This Order may be cited as the Agricultural and Dairy Machines, Implements and Vehicles (Suspension) Order, 1919."

As regards import restrictions, it was decided that the Agricultural Machinery Department should cease to recommend licences for import and export, and that the Department of Import Restrictions and the War Trade Department should hereafter exercise their powers as regards agricultural and dairy machinery and implements in consultation with the Boards of Agriculture. Arrangements were made to safeguard the importation of the balance of the articles to be imported under the rationing scheme, and in view of the commercial rate of freight falling to the level of the Blue Book Rate all price control was suspended.

At the end of 1918 Mr. Underdown was appointed liquidator for agricultural machinery contracts, the liquidation of which presented fewer difficulties than those encountered by other Departments owing to the products involved being of a standard nature available for use under normal conditions.

The work of the Department virtually came to an end in February, 1919.

It may be claimed that as a result of its work the necessary supply of vital agricultural and dairy machinery and other articles necessary to food production was safeguarded while numerous expressions of appreciation from the trade may be taken as an indication that control as regards such matters as standardisation, which was vigorously encouraged both under Mr. Edge and Mr. Underdown, was not without its advantages to the trade in bringing about improvement in production methods, including costing, and in helping to place both the manufacturing and distributing side of the industry on an improved basis. Steps were taken to ensure that the information in the hands of the Department was made available to the Board of Agriculture, the Board of Trade, and other Government Departments likely to be interested directly or indirectly in the future of the industry.

APPENDICES.

APPENDIX I.

(See above, p. 3.)

Control of Manufacture—Order of 10 January, 1917.

THE MINISTER OF MUNITIONS GIVES NOTICE that in exercise of the powers conferred upon him by the Defence of the Realm (Consolidation) Act, 1914, the Defence of the Realm (Amendment) No. 2 Act, 1915, the Defence of the Realm (Consolidation) Regulations, 1914, and all other powers thereunto enabling him, he hereby prohibits as from the date of this Order until further notice any person from carrying out, except under and in accordance with the terms of a permit issued under the authority of the Minister of Munitions, any work consisting in the manufacture or erection of any machine, implement, vehicle, or other article or any part thereof, designed or adapted or commonly used for agricultural or dairy purposes, provided that this Order shall not prevent the completion of any work remaining to be done under a contract in writing entered into before the date hereof upon any article of the nature aforesaid intended for use in this country, or the carrying out of any necessary repairs.

On behalf of the Minister of Munitions,

H. C. B. UNDERDOWN,

The Director of the Agricultural Machinery Department.

APPENDIX II.

(See above, p. 3.)

Form of Permit to Manufacture.

PERMIT TO MANUFACTURE UNDER ORDER OF 10 JANUARY, 1917, ISSUED BY THE MINISTER OF MUNITIONS, AND RELATING TO MACHINES, IMPLEMENTS, VEHICLES, OR OTHER ARTICLES FOR AGRICULTURAL OR DAIRY PURPOSES.

To:

Subject to the following regulations, but not otherwise, you are hereby permitted to manufacture the articles specified on the back hereof.

(1) *Home Trade only.*—Nothing intended for export or unsuitable for Home Trade shall be manufactured under this permit.

(2) *Unnecessary Types and Fittings.*—All unnecessary types, fittings, and jointing and all unnecessary finish in the way of polish and machining shall be omitted.

(3) *Sub-contracts.*—Without the sanction in writing of the Ministry of Munitions first obtained, no privilege or benefit of this permit shall be transferred to, or used by, or for the advantage of, any person other than the permit-holder.

(4) *Records.*—The actual sale price of, and the material used in the construction of all articles manufactured under this permit, shall be accurately recorded in proper books of account kept by the permit-holder, and these and all his other books of account shall be open for inspection by the Representative of the Ministry at all reasonable times, and copies of any portions thereof, including a return of orders received, shall be furnished to this Department as and when required.

(5) *Monthly Returns.*—During the continuance of the permit a return on A.M.D. Form 107 properly completed shall be made monthly to this Department recording the number of articles (if any) manufactured during the respective month, whether sold or not; the returns so furnished shall conform with the records in the permit-holder's books.

(6) *Price.*—No article manufactured under this Permit shall, without the consent in writing of the Director of this Department, be sold at a price exceeding the net invoice price for such article to Agents ruling in the permit-holder's business on 1 April, 1918, or to any User, at a price exceeding the net invoice price for any such article to Users ruling in such business on 1 April, 1918, and the permit-holder shall,

in accordance with any directions which may from time to time be given him by the said Director, reduce or otherwise modify any price or prices.

This regulation shall not apply to the sale of—

(1) Any Agricultural Implement at a price not exceeding £2.

(2) Any Dairy Implement at a price not exceeding £1.

(3) Any part of an Agricultural or Dairy Implement at a price not exceeding 10s.

(7) *General.*—All additional regulations or modifications issued from time to time, by circular or otherwise, shall be observed by the permit-holder as though they were embodied in this permit.

APPENDIX III.

(See above, p. 3.)

Table Showing Permits Issued and Materials Allocated.

1 *January*, 1919.

	1917.	1918.	Total.
Number of Permits issued ..	1,334 ..	3,323 ..	4,657
Number of Permit Holders ..	971 ..	1,628 ..	2,599
Materials allocated.	Tons.	Tons.	Tons.
Cast iron	12,492 ..	54,335 ..	76,827
Wrought iron..	5,901 ..	29,341 ..	35,242
Malleable castings	2,088 ..	11,562 ..	13,650
Mild steel	9,044 ..	29,985 ..	39,029
Hard steel	— ..	1,190 ..	1,190
Spring steel	— ..	613 ..	613
Boiler plates	— ..	242 ..	242
Shell discard	700 ..	10,051 ..	10,750
Crucible cast steel	2 ..	75 ..	77
Steel castings	— ..	235 ..	235
Tinned sheets..	209 ..	2,086 ..	2,295
Tinned plates..	208 ..	2,046 ..	2,254
Copper	98 ..	338 ..	436
Brass	162 ..	619 ..	781
Solder	70 ..	285 ..	355
Galvanised steel sheets (defective)	54 ..	64 ..	118
Tin	8 ..	64 ..	72
Zinc	1 ..	102 ..	103
Spelter	8 ..	90 ..	98
Totals	31,045 ..	153,323 ..	184,367

APPENDIX IV.

(See above, p. 16.)

Control of Sale—Order of 21 June, 1918.

The Minister of Munitions, in exercise of the powers conferred upon him by the Defence of the Realm Regulations and all other powers thereunto enabling him, hereby orders as follows :—

1. On or after the First day of July, 1918, no person shall offer to sell, sell or deliver any Agricultural or Dairy Implement not purchased by him direct from the manufacturer thereof, unless he shall hold a permit from the Minister of Munitions for such sale or delivery.

2. On or after the First day of July, 1918, no person shall offer to sell, sell or deliver any Agricultural or Dairy Implement purchased by him at a price exceeding the net cost thereof, delivered to him by more than 17½ per cent. where such net cost amounts to £40 or upwards, and by more than 25 per cent., where such net cost amounts to less than £40, provided that this clause shall not apply to any offer, sale or delivery of—

(1) Any Agricultural Implement at a price not exceeding £2.

(2) Any Dairy Implement at a price not exceeding £1.

(3) Any part of an Agricultural or Dairy Implement at a price not exceeding 10s.

3. It shall not be made a term or condition of the sale of any Agricultural or Dairy Implement that the purchaser shall purchase or cause to be purchased any other article or goods.

4. Every person dealing in Agricultural or Dairy Implements shall keep a true and complete record of all such dealings, and the price at which every Agricultural or Dairy Implement shall be purchased or sold by him, and shall furnish to the Director, Agricultural Machinery Department, Ministry of Munitions, as and when required by him, such returns as to Agricultural and Dairy Implements purchased, sold or delivered by or to him at such times and in such form as the said Director shall from time to time direct. All such records shall be open for inspection by a representative of the Ministry of Munitions at all reasonable times.

5. For the purposes of this Order the expression " Agricultural Implement " shall mean any machine, implement, vehicle or other article or part thereof, designed or adapted, or commonly used for agricultural purposes ; and the expression " Dairy Implement " shall mean any machine, implement, vehicle or other article, or any part thereof, designed or adapted or commonly used for dairy purposes, but no second-hand machine, implement, vehicle or article shall be deemed to be included in the above definitions.

6. All applications for permits under this Order shall, so far as they relate to Agricultural or Dairy Implements in England, Scotland, and Wales be addressed to the Director, Agricultural Machinery Department (Price Control Section), Ministry of Munitions, 8, Northumberland Avenue, London, W.C. 2, and, so far as they relate to any such implements in Ireland, to the Secretary, Department of Agriculture and Technical Instruction, Upper Merrion Street, Dublin.

7. This Order may be cited as the Agricultural and Dairy Machines, Implements and Vehicles (Sale) Order, 1918.

NOTE.—In conjunction with this Order the Minister of Munitions has taken steps to control the prices chargeable by manufacturers for all Agricultural and Dairy Machinery and Implements, and no manufacturer will be allowed to receive any part of the percentages referred to in clause 2 which are chargeable in addition to the manufacturer's prices to cover agency, distribution and other selling expenses.

APPENDIX V.

(See above, p. 19.)

Table Showing Authorised Increase of Prices.

Machine or Implement.	Maximun percentage increase considered reasonable between 1/1/14 and October, 1918.	Average percentage increase authorised.	
		List Price.	Net Price To Agents.
	Per cent.	Per cent.	Per cent.
Binders	150	—	157
Chaff cutters	104	90	101
Crushing and grinding mills	94	80	95
Cultivators	100	71	90
Drills	88	65	80
Distributors	90	72	83
Elevators and hay loaders	109	78	77
Harrows	90	80	88
Haymakers	75	52	70
Horse rakes	90	60	80
Hoes	90	76	94
Mowers and reapers	100	73	93
Oil Cake mills	104	91	104
Ploughs	95	81	93
Potato diggers	80	70	82
Rakes (side delivery)	80	62	82
Rollers	80	65	81
Root cutters and pulpers	103	90	103
Swath turners	65	40	63
Threshers	122	112	114
Winnowers	144	108	122

APPENDIX VI.

(See above, p. 2.)

The Organisation of the Agricultural Machinery Department, November, 1918.

Mr. H. C. B. UNDERDOWN,
Director.

IMPORTS AND EXPORTS.
Mr. W. MILES,[1]
Section Director.

MANUFACTURING.
Mr. G. F. MUNTZER, O.B.E.,[2]
Section Director.

PRICE CONTROL.
Mr. J. J. URE,
Section Director.

(Under Manufacturing:)

CONTRACTS.
Mr. H. H. CROCKFORD.

PERMITS.[3]
Mr. T. W. WOOLLEN.

STATISTICS.
Mr. F. V. JAMES.

MATERIALS.
Mr. G. CRESSY.

PRODUCTION.
Mr. E. H. ARNOTT.

[1] Mr. W. Miles succeeded Mr. D. Citroen in January, 1918.
[2] Mr. G. F. Muntzer, O.B.E., succeeded Mr. P. O. L. Perry, C.B.E., in April, 1918.
[3] This Section originally included the Materials Section.

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